CHAPTER 8
SUBSYSTEM QUALIFICATION

Subsystem qualification requirements and procedures for specific subsystem airworthiness qualification are identified. Also identified are subsystems that normally undergo subsystem qualification.

8-1 INTRODUCTION

The procedures used to establish and carry out subsystem qualification as part of an overall qualification program are presented in this chapter. The objective of subsystem qualification is to ensure, within reason, that the subsystem meets or exceeds the specified performance. A subsystem can be airworthy but not necessarily qualified. More often than not, subsystems are not qualified prior to first flight. Subsystem-level analyses and tests are used to assure adequate safety characteristics and also to support a preflight airworthiness determination. Early identification of operational suitability and performance deficiencies allows time for the development process to correct these deficiencies. Qualification tests should be performed on production or near-production hardware. Some requirements can be tested practically only at the subsystem level. In these cases subsystem-level qualification is used to demonstrate formal compliance with design and/or specification requirements. Subsystem test articles and various test environments are discussed in detail in the paragraphs that follow.

In general, test setups at the subsystem test level include bare bench, hot mock-up, palletized flight test, and surrogate host flight testing. Bare bench tests are tests in which the subsystem is assembled and interfaced functionally with its components. Their purpose is to determine that the subsystem components perform and interface functionally as intended. This setup is not necessarily representative of the positioning and environment of the actual hardware. Hot mock-ups constitute the next higher level of integration and representation of the actual subsystem configuration and actual environment. In this examination subsystem components are positioned relative to each other as they would be on the air vehicle. Iron bird and tied down air vehicle testing are forms of hot mock-ups. Environments are also representative of actual operation. Palletized flight testing is performed by integrating a subsystem (usually electronic or avionic) onto a pallet for ease of installation and removal from an air vehicle and performing flight testing to determine subsystem performance in an actual flight environment. Another method of flight testing at the subsystem level is to integrate a subsystem into a surrogate host, i.e., an air vehicle different from air vehicles for which the subsystem is ultimately intended. This might be necessary if the air vehicle is not available due to schedule or other programmatic issues. The surrogate host serves as the platform from which subsystem-level characteristics can be derived in a flight environment without the necessity for the actual air vehicle for which the subsystem is intended.

Subsystem-level tests may be performed to satisfy both survey and demonstration requirements. Surveys are used to obtain data to establish the performance capabilities of the subsystem or system. Demonstrations are used to provide data that show that a performance requirement has been met. Par. 2-4 provides further discussion of the differences between surveys and demonstrations.

Environmental and electromagnetic interference (EMI) qualification tests are normally performed at the component level. Chapter 7 provides discussion and guidance on performing these tests. In some cases it might also be desirable to perform tests at the subsystem level to account for factors such as interconnecting cables and the ground plane. Electromagnetic compatibility (EMC) and electromagnetic vulnerability (EMV) tests are always performed at the system level. Chapter 9 provides discussion and guidance on performing electromagnetic environment effects (E^3) tests.

8-2 ENGINE, TRANSMISSION, AND DRIVE SUBSYSTEM QUALIFICATION

The engine, transmission, and drive subsystem airworthiness and typical qualification test objectives are to demonstrate that these subsystems satisfy the performance and interface requirements of the air vehicle, detail, and airworthiness qualification specifications. The qualification requirements fall generally under the categories of efficient power output and transmission capability under specified operating conditions and at specified reliability levels.

Typical test objectives include the measurement and performance demonstration of horsepower, torque, specific fuel consumption, efficiency, and reliability. Specific parameters are discussed in the subparagraphs that follow.

Aeronautical Design Standard (ADS)-9, *Propulsion System Technical Data*, (Ref. 1) may be used as a source of information to determine the data needed to evaluate the contractor's capability to meet specified interface and performance requirements. The procuring activity (PA) may reference this ADS as a source of information but should not require compliance. The contractor is responsible for design. These data provide a basis for technical proposal presentations, for their evaluation, and for evaluation of analytic reports. The ADS prescribes that a general description of the overall propulsion subsystem should be submitted to define configuration, arrangement, and functional relationships. It requires the analysis of the rotorcraft drive subsystem's torsional stability showing both gain margin and phase margin throughout the operational envelope. It also requires air vehicle manufacturers to supply all installation performance losses including the total installed effect of the losses on engine performance. For the engine and auxiliary power unit (APU) starting subsystem, a detailed description is required and should include schematics to show component location and associated hardware used in the installation. Any special operating procedures should be defined and include both normal and extreme temperature cases. Required fuel subsystem data necessary to verify fuel system design are required as well. For propulsion system cooling, engine and APU compartment cooling analyses and transmission and gearbox cooling analyses are required. Additionally, data describing the exhaust and infrared (IR) suppressor subsystem; the engine air induction subsystem; the fire detection, extinguishing, and protection subsystem; the bleed air and pneumatic subsystem; the heating and cooling (environmental control) subsystems; the drive subsystem; and the APU are needed.

ADS-39, *Prequalification/Substantiation Requirements for Alternate Manufacturing Sources of Helicopter Drive System Components*, (Ref. 2) provides requirements for validating that drive system components procured from a source other than the initially qualified manufacturer of the component (an alternate source) satisfy specified performance and interface. ADS-39 (Ref. 2) requires the substantiation of the equivalence of the product to the original manufacturer's component in terms of service life, strength, durability, form, fit, and function. The process of prequalification of alternate sources includes dimensional substantiation, material substantiation, process substantiation, and manufacturing process control. Dimensional substantiation ensures that all drawing dimensions, limits, and tolerances are followed. Material substantiation requires that castings and forgings be procured only from sources that have been previously approved by the Government for each specific component. Process substantiation ensures that all processes used in the component fabrication are performed by sources that have been previously approved by the Government for each specific component. Processes consist of heat treatment, shot peening, finishing, coatings, plating, and all other processes used to manufacture the part. Manufacturing process control requires that a process sheet listing the sequence of operations, operation descriptions, parameters, inspection stations and criteria, and specific equipment used to produce the equipment be included in the inspection report and submitted to the procuring service. Upon approval of the process results, the process sheet, including all changes made during the substantiation effort, is classified as "frozen planning". Any proposed changes to the "frozen planning" must be submitted to the procuring service for approval. ADS-39 (Ref. 2) specifies, by air vehicle, the specific substantiation requirements for each drive subsystem component.

ADS-50-PRF, *Rotorcraft Propulsion Performance and Qualification Requirements and Guidelines*, (Ref. 3) establishes the general performance, interface, and related validation requirements for qualification of US Army rotorcraft propulsion subsystems. For the purposes of this ADS "propulsion subsystems" includes engine and auxiliary power unit installations and start, fire detection and extinguishing, drive, fuel, environmental control, and hydraulic subsystems. Specific performance requirements should be included in the contract and its related specifications.

Engineering evaluation tests required by the standard include

1. Customer bleed air
2. Engine heat rejection and oil cooling
3. Oil flow interruption test
4. Engine electrical power failure test
5. Engine vibration survey
6. Starting torque
7. Maintenance test
8. Verification of correction factors.

Preliminary Flight Rating Test (PFRT) requirements described in the standard include

1. Endurance test
2. Engine component tests
3. Altitude tests
4. Structural tests.

Qualification test requirements of the standard include

1. Endurance test
2. Engine component tests
3. Altitude tests
4. Engine environmental and ingestion tests
5. Engine characteristics and fuel tests
6. Structural tests.

US Navy MIL-E-8593, *General Specifications for Turboprop Aircraft*

Engine, (Ref. 4) US Air Force MIL-E-87231, *Turbojet and Turbofan Aircraft Engines*, (Ref. 5) are additional sources of information. A triservice performance specification will replace these documents.

8-2.1 ENGINE PERFORMANCE

The engine performance airworthiness and typical qualification test objectives substantiate that the engine subsystem and its installation into the airvehicle meet the performance requirements of the system specification.

ADS-25, *Engine Performance Data*, (Ref. 6) defines the required format for presentation of gas turbine engine performance characteristics, ratings, and performance data. ADS-25 (Ref. 6) requires that unless otherwise specified, engine performance characteristics are to be based on

1. A fuel having a lower heating value of 42,565 kJ/kg and otherwise conforming to MIL-T-5624, *Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8ST*, (Ref. 7) and oils conforming to MIL-L-23699, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base*, NATO Code #0-156, (Ref. 8) and MIL-H-7808, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base*, (Ref. 9).
2. US Standard Atmosphere, 1976 (geopotential altitude)
3. No inlet air distortion
4. An inlet pressure recovery of 100%
5. The designated exhaust pipe
6. No customer bleed air extraction
7. No accessory power extraction other than that required for continuous engine operation
8. The engine control subsystem specified for the engine and performance predicted on the tolerance of the control subsystem that produces the poorest performance.
9. A shaft power absorber with characteristics specified by the contractor.

ADS-25 (Ref. 6) indicates that performance ratings should be in accordance with Tables IA, IB, IIA, and IIB of AV-E-8593 (Ref. 10) and should be provided in the user's manual or engine specification. The first stage turbine rotor inlet conditions for each rating established at 1.2 km, pressure altitude static, 35°C (95°F) conditions should be constant for all atmospheric and Mach number conditions except when limited by fuel flow, compressor aerodynamics, or torque limits. The delivered shaft power and fuel consumption for 75% maximum continuous power at 70% of rated delivered shaft speed, 0.41 Mach number, 6.0-km standard conditions should be specified.

In addition, ADS-25 (Ref. 6) indicates that engine performance data should be presented in two forms: one in the form of standard atmosphere curves and the other, a computer program suitable for use with a digital computer. The computer program is required to be the primary and forms part of and is to be identified in the applicable engine specification. The performance data are required to cover the operating envelope of the engine.

ADS-26, *Engine Installation Data*, (Ref. 11) is an interface document that describes installation and interface information required for turboshaft engines. It addresses

1. Item diagrams
2. Interface definition including drawings and installation interfaces
3. Moments of inertia
4. Engine mounts
5. Ground handling mounts
6. Engine stiffness
7. Pads and drives

8. Engine surface temperature and heat rejection

9. Engine component limiting temperature

10. Air and gas leakage

11. Engine inlet air subsystem

12. Bleed air subsystem

13. Power absorber to engine interface characteristics.

There are numerous engine power rating conditions that apply to engine power determination. The maximum power of the engine is an operating condition at which the engine is capable of operating for at least an incremental time duration of 10 min. The intermediate power is an operating condition at which the engine is capable of operating for an incremental time duration of at least 30 min. The maximum continuous power is an operating condition at which the engine is capable of operating continuously. Delivered shaft power is the power delivered at the output shaft as measured by delivered torque and delivered shaft speed.

Engine performance measurements include engine power, torque, shaft speed, gas temperature, specific fuel consumption, surge margin, speed burst, speed chop, load burst, and load chop.

8-2.2 TRANSMISSION AND DRIVE PERFORMANCE

Transmission and drive subsystem performance and typical airworthiness and test objectives ensure that the specified air vehicle level and detailed performance requirements have been met. In addition, these tests should verify the interface of the subsystem and airframe, proper lubrication, gear meshing, etc., to ensure prior to flight test that the subsystem will perform as required without catastrophic failure.

Following the component-level bench testing of transmissions, gearboxes, gears, etc., described in Chapter 7, performance testing of the transmission and drive subsystem is typically accomplished on an iron bird or ground tied down vehicle. See subpar. 6-4.3 for a description of the test setups. Either the iron bird or tied down vehicle is suitable for testing the performance of the entire drive subsystem. The rotor subsystems are used to control torque, etc. For initial qualification of a subsystem or complex component, subsystem-level testing is required. Shafting, couplings, and bearings external to the main transmission(s) and other gearboxes, which constitute the mechanical interconnect between these subsystem components, are verified operationally in conjunction with the transmission and drivetrain subsystem. Subsystem-level vibration testing should be accomplished as described in subpar. 8-2.3. Compatibility of the engine, drivetrain, and airframe should be demonstrated both on the ground and in flight; see subpar. 9-3.1. Performance of engine and drivetrain controls should be demonstrated both on the ground and in flight; see subpar. 9-3.1.1. Typically, 50 h of pre-first flight testing are accomplished at the expected flight load spectrums. Also 400 rotor brake stops should be demonstrated. This is usually followed by 1450 h of reliability and endurance flight testing also at expected flight load spectrums. Periodic teardown inspections are typically required. The test program should also demonstrate that the overrunning clutch is capable of 200 engagements without adjustment and 2400 engagements without replacement. For information about vertical takeoff and landing air vehicles and short takeoff and landing air vehicles, see MIL-T-5955, *Transmission Systems, VTOL-STOL, General Requirements for*, (Ref. 12).

8-2.3 ENGINE, TRANSMISSION, AND DRIVE VIBRATION DETERMINATION

Typical engine, transmission, and drivetrain airworthiness and qualification test objectives include validation that performance requirements, such as critical speeds, operational and design limit misalignment, and resonance frequencies, etc., have all been satisfied. Also included are validations that engine components and drivetrain natural frequencies are sufficiently removed from propeller frequencies, rotor and blade operational frequencies, weapons rates of fire, and starter-generator switching rates, etc. Typically, the contractor conducts a free vibratory test of the engine to obtain the frequency response characteristics, natural frequencies, and mode shapes. Special intake or exhaust duct configurations or other kits that significantly change engine mass and other characteristics are also investigated. Rotor subsystems, engine controls, and combustion subsystems all introduce lags that decrease the stability of the drivetrain. Torsional instabilities result in unwanted vibrations; hence the contractor should demonstrate by test that there are adequate gain and phase margins throughout the operational envelope. Objectively, stable gain margins should be available at frequencies corresponding to a phase angle of –180 deg and main rotor and tail rotor resonance at any operating condition. Stable phase margins, measured at the gain crossover frequency, should be demonstrated at all flight conditions. Also testing should demonstrate acceptable transient response characteristics and steady state error characteristics of the control subsystem. The contractor should propose a test plan to achieve these objectives. Typical measurements include frequencies, amplitudes, direction, pedal positions, collective positions, fuel flow, strains, and engine and rotor torque. Fig. 8-1 provides a typical format for the summary of propeller vibratory stress.

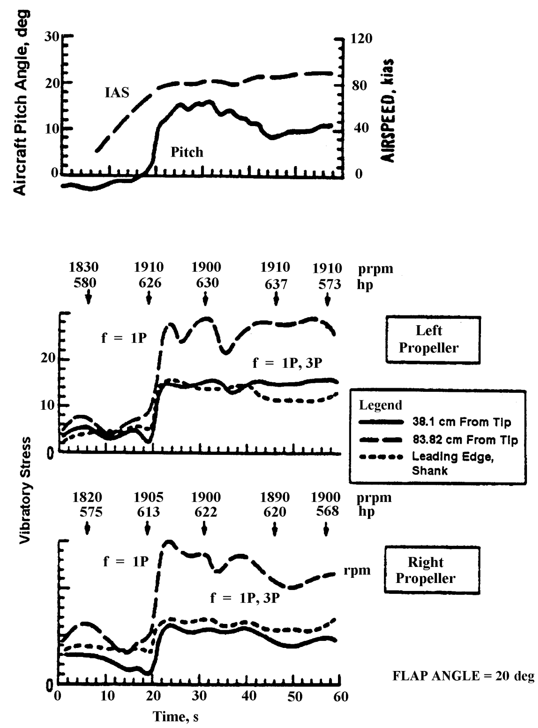

Figure 8-1 Propeller Vibratory Stress Survey Summary

8-2.4 ENGINE, TRANSMISSION, AND DRIVE ENDURANCE

The engine, transmission, and drive subsystem preflight airworthiness and typical qualification test objective is to substantiate that these subsystems can be operated at their required performance levels throughout the anticipated life of the subsystems without catastrophic failures. The endurance test setup should duplicate to the greatest extent possible the actual operating conditions and environment of the engine and drive subsystems. This setup should be essentially the same as the performance test setup described in subpar. 8-2.2. The extended time, or endurance, tests are usually based on anticipated flight spectrum conditions.

These tests are used not only to substantiate the life of the subsystem, but the results of these tests can also be used to establish limitations of the subsystems and to identify failure modes and inspection criteria.

Typical test measurements include the data necessary to establish and maintain the required test spectrum, such as engine and rotor torque, fuel flows, engine and rotor speeds, and frequencies and amplitudes of vibration levels. Endurance tests typically include specified inspection intervals to determine wear patterns and to inspect for indications of impending failure.

8-2.5 AUXILIARY POWER UNIT

The auxiliary power unit airworthiness and qualification test objective is to substantiate that the subsystem will satisfy specified performance requirements, such as performing reliably at the required power levels and under the required environmental conditions.

ADS-17, *Power Units: Aircraft Auxiliary Gas Turbine, Type IV*, (Ref. 13) provides general requirements for gas-turbine-type APU. Qualification requirements include a 200-h endurance test. The first 100 h of test should be conducted using fuel conforming to MIL-T-5624 (Ref. 7) Grade JP-4 and oil conforming to MIL-L-7808 (Ref. 9). The second 100 h should be conducted using fuel conforming to MIL-T-5624 (Ref. 7) Grade JP-5 and oil conforming to MIL-L-23699 (Ref. 8). An altitude test that consists of operation and air starting checks at selected conditions should be performed. Further, tests to demonstrate performance capability at low temperature and tests to demonstrate the use of emergency fuels are typically required. These tests should include starting capability and engine operating temperatures. Typical measurements for auxiliary power units made during these tests include speed, power, torque, and specific fuel consumption.

8-2.6 FIRE DETECTION AND EXTINGUISHING

The airworthiness and typical qualification test objective for the engine and auxiliary power unit mounted fire detection and suppression subsystem is to demonstrate ultimately that an engine or APU fire can be reliably detected and suppressed. Also some means should be provided by which to check the fire detection and suppression subsystem to assure its availability when needed.

Subpar. 9-3.6 provides a discussion of a system-level qualification requirement for fire detection and extinguishing.

The parameters to be assessed during qualification testing include but are not limited to sensor and suppression capability. The sensors should be capable of detecting a fire condition without initiating false alarms during normal operation. Fire suppression capabilities to be determined by test are the ability of the subsystem to provide fire extinguishing materials in sufficient quantity and at a sufficient rate to suppress the fire. The proper location of fire sensors and extinguishers must also be addressed.

8-3 FUEL SUBSYSTEM QUALIFICATION

The fuel subsystem includes all components whose primary function is to store, supply, sense, or control fuel in the air vehicle. The fuel subsystem airworthiness and typical qualification test objectives are to demonstrate the operating characteristics of the subsystem both on the ground and throughout the flight envelope. These objectives include but are not limited to the ability of the subsystem to store and distribute the fuel in a manner that allows achievement of air vehicle system-level requirements.

8-3.1 FUEL CAPACITIES

Typical qualification test objectives are to substantiate the fuel capacity and to determine usable and unusable fuel within the subsystem. The capacity of each internal and external tank should be determined and compared with specifications. The tanks should be filled with the air vehicle at its normal ground attitude.

Measurements include fuel capacity and the rate at which fuel can be delivered into the air vehicle's fuel subsystem, fuel probe accuracy, and center of gravity (CG) changes with fuel usage. Fuel tank capacity should include a measurement in gallons to fill the tank. In addition to the gallon measurement, fuel temperature and specific gravity should be taken before, during, and after the capacity check and should be used to determine fuel weight in pounds. Fuel quantity probe accuracy tests and calibration may be conducted during the fuel capacity test. Center of gravity tests should be conducted with the air vehicle positioned in the normal flight attitude. All available fuel should be removed from the air vehicle in 50-lb increments, and the CG recorded at each increment of fuel level.

8-3.2 REFUELING AND DEFUELING

The refueling and defueling airworthiness and typical qualification test objectives are to substantiate that the air vehicle can be safely fueled and defueled within the time requirements specified.

Refueling is normally accomplished using one of the following techniques: gravity refueling, pressure refueling, or suction refueling. Gravity refueling relies on the force of gravity to cause fuel to flow from its source to the air vehicle fuel subsystem. A pressure refueling system allows faster fueling by delivering the fuel from its source to the air vehicle fuel subsystem under pressure from the source. Suction fueling depends on the fueling subsystem of the air vehicle to suck fuel from its source into the air vehicle.

Defueling is typically accomplished on the ground and requires the use of ground support equipment. Gravity refueling and defueling rely on the force due to gravity to cause fuel to flow. This capability is needed at commercial airfields and in North Atlantic Treaty Organization (NATO) countries. There is a NATO standard nozzle. Pressure refueling is a term associated with closed circuit refueling. With closed circuit refueling there should be no vapor loss at the nozzle-to-receiver interface. Hot refueling, which is typically accomplished with engines running and rotor blades turning, is a form of pressure refueling. One objective of qualification testing is to demonstrate that pressure and hot refueling can be accomplished safely within the specified total elapsed time.

Testing should be conducted at incremental nozzle inlet pressures, and flow rates and service times should be measured and compared to the detail specification. Tests should also be conducted to verify the automatic shutoff function operates properly during refueling operations. Defueling should be conducted at the maximum discharge flow rate.

Measurements for refueling include fuel flow rates and pressures.

8-3.3 SLOSH AND VIBRATION

The slosh and vibration airworthiness and typical qualification test objective is to substantiate that air vehicle maneuvering will not cause adverse effects from fuel slosh and vibration. Slosh and vibration cause changes in the location of the fuel with a resultant change in the center of gravity of the air vehicle. Significant deviations in center of gravity should be controlled to prevent adverse impact on the dynamics of the air vehicle.

Measurements for slosh and vibration include the dynamics of air vehicle fuel under various air vehicle dynamic conditions. Measurements on the ground should include but are not limited to measurements of center of gravity changes with air vehicle attitude change. In-flight tests should include measurements of change in vibration levels and qualitative evaluation of changes in handling qualities during specified dynamic maneuvers.

8-3.4 FUEL SUPPLY AND FUEL TRANSFER

The fuel supply and transfer airworthiness and typical qualification test objective is to substantiate that the fuel subsystem is capable of supplying the engines with adequate fuel to sustain uninterrupted engine performance during all phases of air vehicle system operation.

Fuel may be supplied to the engine through suction, pressurization, or boost pumps. Suction-type fuel subsystems use the engine or other suction device to “suck” fuel out of the fuel tank. Pressurization-type fuel subsystems maintain pressure in the fuel tank and “push” fuel to the engines. Boost-pump-type subsystems push fuel to the engines but without pressurizing the tank. In addition, it might be necessary to transfer fuel from various storage locations on the air vehicle in flight. Fuel supply and transfer characteristics are typically measured in terms of fuel flow rates and pressures. Tests should be conducted at the full range of expected environmental conditions in order to assess the impact of fuel temperature and ambient pressure conditions on the performance of the fuel transfer subsystem. The effects of fuel boost pump and transfer pump failures should be determined by analyses and tests, if possible. Typically, a failure might result in a low flow rate or no fuel flow. The effects may vary for different fuel temperatures, ambient pressures, and air vehicle weights. Hence effects should be determined for the entire flight spectrum. Adverse effects might include engine surge, flameout, and instabilities in the engine control subsystem. The failure of a transfer pump might affect air vehicle stability and control.

8-3.5 FUEL SYSTEM CRASHWORTHINESS

The airworthiness and typical qualification test objective for crashworthy fuel subsystems is to demonstrate that the subsystem is capable of withstanding a forced landing or crash within specified limits of the installation without breaking loose, leaking, or resulting in fire. Additional objectives are to demonstrate adequacy of the rollover vent valves, self-sealing fuel lines and tanks, breakaway fuel lines and valves, and electrical components. Typically, fuel cells are drop tested from a specified height. Breakaway self-sealing valves and all frangible fittings are typically qualified on the basis of tests conducted at the component level and substantiated by qualification test reports, such as a breakaway self-sealing valve qualification test report. Test requirements and pass-fail criteria are usually specified in test plans that are prepared by the contracting authority (CA) and submitted for the approval of the PA. Required plans and reports should be defined in the statement of work and listed in the contract data requirements list (CDRL). Qualification should include structural, dynamic, and slosh and vibration analyses and testing. Also qualification includes functional analyses and testing of the fuel subsystem. Analyses and tests should be sufficient to demonstrate that the airframe and tanks are capable of reacting to all crash-related loads and forces associated with the overturning moment, etc. Analyses should start with a balanced free body diagram. Typical measurements include weights, forces, fuel pressure, and surges. For additional information refer to subpars. 8-3.6, 8-3.8, and 8-3.9. Also refer to Test Report (TR) 89-D-22E, *Aircraft Crash Survival Design Guide, Vol. 5, Aircraft Postcrash Survival*, (Ref. 14) and MIL-STD-1290, *Light Fixed and Rotary Wing Aircraft Crash Resistance*, (Ref. 15). Other requirements might be specified in the contract, which must be followed.

8-3.6 INERTING SYSTEMS

The inerting subsystems airworthiness and typical qualification test objective is to substantiate that the subsystems can be purged of fuel concentrations to allow for safe maintenance operations. Inerting subsystems include application of inert gas into the fuel subsystem to reduce the explosive atmosphere caused by fuel fumes.

Measurements for inerting subsystems include the capability of the subsystems to prevent the fuel subsystem from catastrophically exploding due to outside ignition. This is accomplished by measuring oxygen and/or hydrocarbon levels after inerting the subsystem. Subpar. 8-3.8 provides additional discussion of explosion protection.

8-3.7 AERIAL REFUEL

The airworthiness and typical qualification test objectives for aerial refueling subsystems are to demonstrate ultimately that the receiver air vehicle can rendezvous with tanker aircraft, join up, and safely transfer fuel from a variety of tanker aircraft and under a variety of environmental conditions. Thus qualification efforts are needed at both the subsystem and air vehicle system level. Also it should be possible to maintain weight and balance control throughout the fuel transfer operation. An automatic fuel management subsystem, fuel quantity gages, valves, and transfer pumps might be needed. Navigational aids and communications subsystems should be adequate for rendezvous. These subsystems and components might add to the overall qualification effort. Takeoffs and landings, slope landings, taxi operations, and in-flight operations should be demonstrated. Aerial refueling should be possible during daylight and darkness; aerial refueling with night vision goggles should be possible. Typically, qualification includes structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, and human factors analyses and testing. Also qualification includes functional analyses and testing of the aerial refueling subsystem. The ability to dissipate safely static and lightning-strike-related electricity should be analyzed and demonstrated. Crashworthiness of the host air vehicle should not be degraded. Flight operations typically include tanker day and night engagements and disengagements, day and night fuel transfer operations, and engagements and fuel transfer in light to moderate turbulence. Except for a single-engine receiver air vehicle, refueling should be possible with one engine in the receiver air vehicle inoperative. Aerial refueling is a multiservice operation. Much planning and coordination are normally needed to avoid costly delays. Typical measurements include electrical grounding, probe loads, vibrations, fuel pressures and surges, flow rates, temperatures, and weight. Other requirements may be specified in the contract.

8-3.8 EXPLOSION PROTECTION

Explosion protection includes all measures that are included in the air vehicle design to reduce the risk of explosion. This protection is provided through means such as ballistic tolerance to prevent fuel spillage, static electric charge prevention and lightning strike protection through use of proper grounding and material, and vent-drain features designed to prevent a buildup of explosive atmospheres. Also all electrically operated components should be properly grounded.

The explosion protection airworthiness and typical qualification test objective is to substantiate that these subsystems satisfy the performance requirements specified in the contract and Airworthiness Qualification Specification (AQS). Explosion protection systems assessments either provide the necessary protection or they do not. Test results are either go or no-go.

8-3.9 AUXILIARY FUEL

The US Army uses auxiliary fuel subsystems to enable its air vehicles to have greater range. These auxiliary fuel subsystems can be used for self-deployment and be removed later. The airworthiness and typical qualification test objectives for auxiliary fuel subsystems are essentially the same as those for the basic crashworthy fuel subsystem, which is discussed in subpar. 8-3.5. Auxiliary fuel tanks can be internally or externally mounted. Internally mounted tanks are usually mounted within the cabin and cargo area. These internally mounted tanks should be carefully vented to prevent fumes and vapors from entering the cabin and also to ensure vented fumes and fuel do not enter the engine and other critical areas. Also the vents should be properly sized to prevent tank overpressurization in the event of a high-level shutoff valve failure. Externally mounted tanks are usually mounted on pylons, which are jettisonable. External tanks should satisfy all aeromechanical, aeroelastic, and aerodynamic performance requirements. It should be possible to maintain weight and balance control throughout fuel transfer operations regardless of the type of tank and mounting. An automatic fuel management subsystem, fuel quantity gages, valves, and transfer pumps might be needed. These subsystems and components might add to the overall qualification effort. Thus qualification efforts are needed at both the subsystem and system level. Typically, qualification includes structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, and human factors analyses and testing. Also qualification includes functional analyses and testing of the auxiliary fuel subsystem. The ability to dissipate safely static and lightning-strike-related electricity should be analyzed and demonstrated. Airworthiness and crashworthiness of the host air vehicle should not be degraded. Typical measurements include weight, forces, vibrations, electrical grounding, fuel pressures and surges, fuel transfer rates, and temperatures. Other requirements may be specified in the contract and the AQS.

8-4 ROTOR, PROPELLER, AND PROPROTOR SUBSYSTEM QUALIFICATION

Rotor, propeller, and proprotor subsystem dynamics are difficult to predict accurately; therefore, qualification is often based on experimental results. The primary purpose of the qualification tests is to validate that structural performance requirements have been met.

This paragraph discusses the following rotor, propeller, and proprotor subsystem qualification testing:

1. Whirl testing
2. Aeroelastic stability and flutter wind tunnel testing

3. Flutter and lift and thrust performance wind tunnel testing
4. Antitorque subsystem performance tests.

Objectives and test descriptions are provided in the subparagraphs that follow.

8-4.1 WHIRL TESTING

The whirl testing airworthiness and typical qualification test objective is to assure that the rotor, propeller, and proprotor subsystems are qualified for installation on the air vehicle for ground and flight tests. Though aerodynamic excitations in test stands are not representative of flight, appropriate information can be learned about stress distributions, critical speed locations, and the boundary of incipient stall flutter. These tests also allow the aerodynamic calibration of main rotor static thrust performance, the stress and motion surveys over the design range of combinations of collective and cyclic pitch and rotor speed, and prove isolated rotor stability.

Rotor whirl towers are available at major contract facilities, such as Boeing Helicopter and Sikorsky Helicopter companies.

8-4.2 AEROELASTIC STABILITY AND FLUTTER

The terms "aeroelastic stability" and "flutter" are synonymous. Both aircraft and rotorcraft might experience flutter. Flutter is a self-exciting vibration. Airworthiness qualification and measurements for aeroelastic stability should not be accomplished at the subsystem level. Aeroelastic stability investigations and testing at the subsystem level are not recommended. The results of such testing are not conclusive. Aeroelastic stability qualification efforts should be accomplished at the air vehicle system level. See par. 9-5 for a discussion of dynamic stability at the system level. The air vehicle system level qualification effort should be accomplished in concert with the aeroelastic modeling effort discussed in subpar. 6-2.5.2.

8-4.3 LIFT AND THRUST PERFORMANCE

Lift is a term that is associated with wings and main rotor subassemblies. Thrust is a term that is usually associated with the propeller, tail rotor, and engine exhaust subsystem. Tilting the rotor produces a propulsive force analogous to thrust. Rotor lift and propulsive force can be directly measured in wind tunnels; however, it is not directly measurable on rotorcraft subsystems. Force models are discussed in subpar. 6-2.4. Typically, rotor subsystem flight performance is estimated based on rotorcraft system flight performance tests at known weights and speeds and with power required being the measured dependent variable. Wind tunnel testing is especially needed when there is concern about stability. (See subpar. 6-2.3.) Full-scale model facilities are available at the AMES Research Center, Moffett Field, CA. NASA/AMES has the biggest facility (24.4- × 36.6-m (80- × 120-ft)) available. NASA/AMES also has a 12.2- × 24.4-m (40- × 80-ft) facility and a reduced scale (2.1- × 3.0-m (7- × 10-ft)) wind tunnel. NASA Langley* has a 4.3- × 6.7-m (14- × 22-ft) reduced scale wind tunnel at its facility. Interference effects result from proximity of the main rotor blade to the fuselage and tail rotor. (See subpar. 6-2.5.1.) Also there are subsystem installation losses. Typical flight test instrumentations are a boom-mounted pitot-static subsystem, strain gages, accelerometers, and flapping angle potentiometers. Signals from the strain gages or other rotating transducers are

*Langley Air Force Base

typically transmitted to the recording instruments through slip rings. Many types of signal conditioning and calibration methods may be selected, as appropriate, to match the types of transducers and equipment available.

8-4.4 ANTITORQUE SUBSYSTEM

The antitorque subsystem counteracts the rotating forces tending to cause the single main rotor rotorcraft to rotate about the centerline of the main rotor mast. Antitorque subsystem types include open tail rotor, ducted tail rotor, and coanda thruster. Testing of antitorque subsystems should include, as a minimum, calibration of the static thrust performance and the stress and motion surveys over the design range of pedal position and required antitorque performance values.

8-4.4.1 Open Tail Rotor

The open tail rotor subsystem airworthiness and typical qualification test objective is to substantiate that this subsystem performs in accordance with specified requirements. The tail rotor subsystem is shaft driven from the main transmission through one or more intermediate tail rotor gearboxes. The purpose of these subsystem-level tests is to determine the ability of the subsystem to provide the necessary thrust.

Test measurements for the tail rotor antitorque subsystem includes the thrust, torque, and installation aerodynamic losses of the tail rotor subsystem. These parameters are usually determined by calculation from measurement input power and direct measurements of strain gages to determine output torque and thrust.

8-4.4.2 Ducted Tail Rotor

The ducted tail rotor airworthiness and typical qualification test objective is to substantiate that this subsystem meets the thrust and other performance requirements for satisfactory antitorque control. Ducted antitorque rotor subsystems are similar to open tail rotor subsystems in that they derive their power from the main transmission. They differ, however, in that they are shrouded as opposed to being open.

The primary measurements for the ducted antitorque subsystems are the rotor thrust and torque, and duct aerodynamic performance produced by the subsystem.

8-4.4.3 Coanda/Thruster Effect Antitorque Subsystems

The coanda/thruster effect antitorque subsystem airworthiness and typical qualification test objective is to substantiate that this subsystem meets the thrust and other performance requirements for satisfactory antitorque control. Coanda effect devices achieve their antitorque effect by using main rotor downwash flowing over an asymmetrical aerodynamic surface (essentially a wing section) with slot blowing positioned such that the lift resulting from the airflow provides an antitorque thrust. The subsystem is generally augmented by a thruster that provides maneuvering forces.

The primary performance measurement for coanda effect antitorque subsystems is again the thrust, coanda force, or torque produced. These parameters are usually determined by direct measurement of strain and calculation of forces and torques.

8-5 HYDRAULIC AND PNEUMATIC SUBSYSTEM QUALIFICATION

Hydraulic and pneumatic subsystem testing is necessary to qualify the installation, to verify the performance capability of the components operating together as a subsystem, and to demonstrate proof of compliance with interface requirements. This testing should follow component testing. Hydraulic applications primarily include flight control and utility functions. Flight control functions are considered to be flight critical and include servo control of cyclic pitch, collective pitch, and directional surfaces. Pneumatic applications may include such functions as engine starting, auxiliary utility subsystems, and emergency backups. Testing of hydraulic and pneumatic subsystems includes the common elements of determining pressures, temperatures, and flow rates.

8-5.1 HYDRAULIC SUBSYSTEM DEMONSTRATION

The hydraulic subsystem airworthiness and typical qualification test objective is to substantiate that the hydraulic subsystems will perform in accordance with their specified requirements.

The hydraulic subsystem should be simulated in mock-up; see Chapter 6. The mock-up should incorporate all hydraulic components and associated plumbing. Hydraulic plumbing should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings. Cyclic, collective, and directional control actuators should be installed with provisions to simulate both the no-load and load conditions. The mechanical linkages, levers, and cabling of the control system should be provided to allow inputs from the cyclic stick, collective lever, and tail rotor pedals. Since these control functions operate continuously and require synchronization and response, the test mock-up should include adequate instrumentation to record and display hydraulic fluid pressure, flow, and temperature at several locations. The mock-up should contain provisions to allow testing of armament and utility functions such as weapon turret azimuth and elevation, cargo hoist, doors and landing gear. Key points for monitoring pressure, temperature, and flow include

1. Reservoir bootstrap pressure
2. Reservoir return
3. Pump suction
4. Pump outlet
5. Branch circuit supply at using component
6. Branch circuit return at using component
7. Accumulator charge.

8-5.2 PNEUMATIC SUBSYSTEM DEMONSTRATION

The pneumatic airworthiness and typical qualification test objective is to substantiate that these subsystems will perform as specified within the required conditions.

The pneumatic subsystem test stand should simulate the actual subsystem installation. Also an iron bird or tied down air vehicle can be used as a test bed. All special test equipment should be installed and any approved modifications completed. The pneumatic subsystem should be properly lubricated and all components and attached linkages and mechanism should be properly adjusted. Testing should allow verification that

1. All specified functions are performed satisfactorily.
2. The movement of all components is smooth and positive.
3. Relief valves, automatic devices that terminate an operation, pressure controls, switches and signals, audible and other warning devices, and similar installations function as intended. Relief valves need not blow off but should not bypass air during normal operation of any component.
4. All indicating devices function and synchronize with the movement of the respective component as specified.

5. The specified functioning pressures are controlled and not exceeded. This may need to be determined at only one or at numerous locations in the subsystem, but should not receive major consideration at any point where unrealistic pressures are obtained on ground test compared with entirely different pressures in flight unless the unrealistic pressures will adversely affect the subsystems during operational use. Pressures may be obtained by normal pressure gages or electronic equipment as applicable.

6. All tubing and fitting joints and component external seals are free from leaks.

7. All lines, fittings, and components are free from excessive movement and chafing.

8. There is full engagement of mechanical locks and catches.

9. The clearance for all moving parts throughout the entire range of movement is such that fouling of adjacent parts cannot occur. Particular attention should be given to flexible connections to ensure that pinching or stretching does not occur.

10. All pneumatically operated doors and closures are flush with surrounding surfaces within the limits specified.

11. Simulated normal flight operating conditions, or any possible inadvertent operations, will not cause subsystem malfunctions.

12. Ambient temperatures are within permissible limits.

All emergency operations should be tested on all subsystems normally operated by the pneumatic subsystem or operated by the subsystem during the emergency. Each subsystem should be inspected for smooth, continuous operation during the changeover from normal to emergency operation.

8-5.3 CABIN PRESSURIZATION

The cabin pressurization airworthiness and typical qualification test objectives are to substantiate that the air vehicle cabin pressure and air quality can be maintained within the required limits.

Measurements for cabin pressurization subsystems include the ability to maintain specified pressure and provide the necessary air exchange to ensure a proper crew environment including temperature and air quality. Testing should provide data that demonstrate an adequate air supply for cooling and demonstrate that moisture does not condense within electronic components. Qualification testing should include testing to demonstrate the effects of decompression and indications of inadequate pressurization.

8-6 LANDING GEAR QUALIFICATION

The purpose of landing gear tests is to demonstrate the landing gear meets the specified performance and interface requirements, such as specified extend and retract times, normal and crash loads, low observables, and compatibility with flotation and skis (if applicable). Typical measurements for landing gear include energy absorption capacity and dynamic load characteristics of the landing gear.

Landing gear subsystem qualification tests include

1. Drop testing
2. Low- and high-speed testing
3. Breaking and brake lock testing
4. Floatation testing
5. Ski testing
6. Retraction and extension testing.

The purpose and objective of each of these tests are discussed in the subparagraphs that follow. (Also see subpar. 6-4.7.)

8-6.1 DROP TESTING

Drop tests of the landing gear and critical backup structure should demonstrate compliance with the air vehicle system specification and also show that the landing gear is capable of absorbing its prorated share of the crash energy according to the contractor's design and the requirements of the air vehicle structural design criteria. Normal load factor and the reserve energy absorption capacity of the landing gear should be demonstrated. Also capacity of the landing gear to land in sand (brownout condition) with some forward velocity should be demonstrated. Fore and aft loading are typically larger when landing in sand. These tests should be conducted to determine the dynamic load characteristics over a representative range of air vehicle weights, angles of attack, and sinking speeds, as applicable to the landing gear type. For wheel-type landing gear they should include sufficient wheel spinup to simulate critical wheel contact velocities. Relevant information concerning the conduct of drop test can be found in MIL-T-6053, *Tests Impact, Shock Absorber Landing Gear, Aircraft*, (Ref. 16). Specific sink speed, wheel speeds, and attitudes should be specified in the subsystem specification. In addition, the shock absorption performance of the gear should be evaluated with the initial metering configuration and with any changes that might improve overall landing performance characteristics. See ADS-29, *Structural Design Criteria for Rotary Wing Aircraft*, (Ref. 17) and ADS-36, *Rotary Wing Aircraft Crash Resistance*, (Ref. 18) for additional information. (Also see subpar. 6-4.7.)

Measurements for drop testing include the forces, velocities, and accelerations applied to the landing gear subsystem along the *x*-, *y*-, and *z*-axes and also measurement by means of strain gages, etc., of their impact on the structural components of the landing gear subsystem and supporting structure. Wheel speeds and attitudes should also be measured. Attitude is usually simulated by means of various inclined planes and wedges.

8-6.2 LOW- AND HIGH-SPEED TESTING

The low- and high-speed testing for landing gear airworthiness and typical qualification testing are conducted on wheeled landing gears to demonstrate the capability of the landing gear to meet the requirements of the landing performance and handling quality characteristics.

Measurements for low- and high-speed testing include loads and stresses imposed on the wheel housings and on the landing gear mounting assemblies at both high- and low-speed landing conditions.

8-6.3 BRAKING AND BRAKE LOCK TESTING

The braking and brake lock airworthiness and typical qualification test objective is to demonstrate that the braking subsystem satisfies performance requirements. The air vehicle should stop within specified limits, etc. In addition, the characteristics of the braking subsystem are assessed with the brakes in a locked condition.

Measurements for braking and brake lock testing include forces and stresses imposed on the landing gear, braking time, and braking distance. Braking data may be obtained in conjunction with the high- and low-speed testing described in subpar. 8-6.2. Braking capability adequate for both stopping and parking the air vehicle on a required slope should also be demonstrated.

8-6.4 FLOTATION TESTING

Flotation gear has been used successfully on rotorccraft and other air vehicles. Flotation gear is either fixed position or deployable. Deployable flotation gear should be capable of automatic inflation after water contact. Typical qualification test objectives and measurements are to validate water buoyancy, drop characteristics, stability and control characteristics at various sea states, stability and control with rotors turning and at rest, weight and balance limitations, effects on aerodynamic performance and aeroelastic qualities, water taxi capabilities, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states, maintainability, and electromagnetic compatibility if the flotation gear is squib activated. The effects of in-flight deployment should be investigated. Also effects on egress should be investigated. Typically, strain gages should be used to evaluate structural adequacy of points of attachment. Typical measurements are weight, buoyancy, drag characteristics, clearance, required power, voltage, stress at attachment points, and vibration characteristics.

8-6.5 SKI TESTING

Snow ski gear has been used successfully on rotorcraft and other air vehicles. US Army air vehicles must be capable of all-weather operation. Typical qualification test objectives and measurements are to validate footprint areas, buoyancy in snow, stability and control characteristics at various wind conditions, visibility in snow with rotors turning, weight and balance limitations, effects of aerodynamic performance and aeroelastic qualities, taxi capabilities under various snow conditions, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various center of gravity positions, maintainability, and effects on in-flight performance. Typically, measurements should include weight, footprint area, structural adequacy of attachment points, vibration characteristics, ground and snow clearances, step height, and aerodynamic and aeroelastic characteristics.

8-6.6 RETRACTION AND EXTENSION TESTING

The retraction and extension airworthiness and typical qualification test objective is to demonstrate compliance with specified performance requirements, such as showing that the landing gear can be reliably extended and retracted under all anticipated flight conditions. The mechanical integrity of all structural members and actuation components is verified.

Measurements for retraction and extension testing include the actuator forces necessary to accomplish extension and retraction and the stresses imposed on the extension and retraction mechanism. These data are typically obtained through strain gage instrumentation. In addition, the time required for extension and retraction is assessed. Time measurements should include static extensions and retractions with the air vehicle on jacks on the ground and with aerodynamic loads in flight.

8-7 ELECTRICAL SUBSYSTEM

The purpose of airworthiness qualification testing is to demonstrate performance capabilities of the electrical subsystem including all of its components and interconnecting circuitry provided for the generation, regulation, storage, control, conversion, and distribution of electrical power. Also included is the embedded software. Typically, all equipment, devices, units, and subsystems that use electrical power should be either installed or emulated.

Both ground and flight testing are needed to demonstrate airworthiness and specification compliance. Ground tests should include all electrical subsystem performance tests and demonstrations that can be performed satisfactorily with the host air vehicle on the ground. Flight tests should include all of the performance tests and demonstrations that cannot be satisfactorily conducted on the ground. The contractor should demonstrate that

1. Operating temperatures of all electrical power and conversion equipment are within design limits.
2. The prime mover has adequate capacity to maintain rated generator loads and overload performance as specified by the contract.
3. Generation and conversion of adequate power from minimum ground idle to maximum engine speed.
4. Voltage regulation, frequency regulation, transient performance, and waveform of the alternating current (ac) subsystem satisfy the performance and interface characteristics of MIL-STD-704, *Aircraft Electric Power Characteristics*, (Ref. 19).
5. Voltage regulation and ripple voltage present in the direct current (dc) subsystem as measured at representative power input terminals of the utilization equipment satisfy the performance and interface requirements of MIL-STD-704 (Ref. 19).
6. Emergency power and alternate emergency electrical circuits are satisfactory for all flight conditions. This demonstration should include performance of the voltage regulator, frequency regulation, and waveform of the ac subsystem and the voltage regulation and ripple voltage content of the dc subsystem.
7. There is satisfactory performance of the fault protection subsystem and detection equipment under specific default conditions
8. The engine starting system is satisfactory.
9. The auxiliary power unit performs satisfactorily.
10. Accessibility for test, adjustment, and servicing is adequate. For information concerning this topic, see MIL-STD-7080, *Selection and Installation of Aircraft Electronic Equipment*, (Ref. 20).

8-7.1 ELECTRICAL POWER TESTING

The electrical power testing airworthiness and typical qualification test objective is to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level.

The electrical load imposed on the power subsystem by each individual electrical subsystem or unit should be measured and the total load on each electrical power subsystem determined. The subsystem or unit should be operated in all modes requiring maximum power. The power required is the steady state demand for the particular mode being considered. Primary power subsystem total load should include the input power to conversion equipment. The conversion (or secondary) power should be supplying its normal loads when its input power is determined.

The contractor should demonstrate that the design, operation, and performance of the primary electrical subsystem satisfies the requirements established by the detail specification and contract. Primary electrical power can be 115/208 V ac 3-phase 400 Hz, 270-V dc, or 28-V dc. The tests should demonstrate

1. Single generator operation and capability
2. Multiple generator operation and capability

3. Load equalization capability
4. Power transfer capability
5. Load transfer capability
6. Supervisory and control functions
7. Operational temperatures
8. Any special operational and design characteristics that may differ from other air vehicle models.

Also they should demonstrate that the primary electrical subsystem and utilization equipment satisfy the performance and interface characteristics of MIL-STD-704 (Ref. 19), including

1. Steady state voltage
2. Ripple amplitude
3. Ripple frequency components
4. Transient performance.

Conversion of secondary power is accomplished by transforming or converting the primary power to another type, usually 28-V dc. The contractor should demonstrate the design, control, and operational features of the conversion power subsystem by appropriate tests. Each individual load imposed on the conversion power subsystem should be measured and the total load on the conversion equipment determined.

Emergency and alternate power loads should be identified and individually measured. The total load on each emergency power source should be determined. Each dc load should be measured in terms of voltage input and amperes of current flow or watts consumed; each ac load should be measured in terms of phase-to-neutral input voltage, amperes of current flow, and either power factor (phase angle) or volt-amperes. It should be demonstrated that the available emergency power and the emergency circuits are satisfactory for all required flight operating conditions of the air vehicle. Emergency power should satisfy the performance and interface characteristics of MIL-STD-704 (Ref. 19) including voltage, frequency regulation, and waveform of an ac subsystem and voltage regulation and ripple voltage content of a dc subsystem. If the emergency dc source is a battery, adequacy of the battery to provide the required power to the emergency circuits for a specified time period at all ambient temperatures should be demonstrated.

A complete demonstration of the fault protection and detection capabilities of the electrical power subsystems should be performed and should include the following:

1. Individual load circuit protection
2. Circuit fault protection
3. Overvoltage protection
4. Undervoltage protection
5. Reverse current protection (CUT OUT)
6. Primary power failure detection
7. Secondary (conversion) power failure protection
8. Reversed polarity protection (dc)
9. Reversed phasing protection (ac)
10. External power protection.

A complete electrical installation environmental test should be conducted on prototype or early production air vehicles. This test should also include a test of the complete starter-generator subsystem. The capability and adequacy of the electrical starting subsystem and installed starting power sources of the air vehicle should be tested to demonstrate that the starting power capability meets the requirements of the detail specification at all ambient temperatures. Also a torsional test should be conducted to demonstrate that both the voltage control regulator frequency and starter driveshaft natural frequency are not coincident with the calculated torsional frequency of the starter-generator shaft. If the starter-generator has a super critical shaft, the contractor should demonstrate either by analysis or test that damping is sufficient to avoid the whirl mode. Typically, strain gage instrumentation is installed on the starter driveshaft so that both steady state and oscillatory torque values can be measured. A slip ring device might be needed on the starter shaft for signal transmittal. Oscillatory torque conditions typically exist in a complicated drive subsystem, such as the combination of the engine accessory drivetrain subsystem and the starter driveshaft subsystem. A reasonable maximum oscillatory torque limit is 10% of the starter pad maximum static torque limit.

Typical objectives of the flight test are to

1. Obtain the operating temperatures of electrical power-generating and conversion equipment for typical flight regimes and conditions
2. Demonstrate the adequacy of the electrical power and conversion equipment under actual flight conditions including but not limited to altitude
3. Demonstrate the capability of the prime mover to maintain the required generator loading
4. Determine the vibrational environment of each generator during flight conditions by monitoring each of the three axes of each starter-generator for vibrational amplitudes and frequencies.

Sufficient flights should be conducted and data obtained to demonstrate the performance and capabilities of the electrical subsystem in flight. The recorded data should be adequate to obtain time history plots. To satisfy these objectives, the following parameters are typically monitored and their values recorded by appropriate instrumentation through the flight regimes and altitudes of a typical mission and as required by the detail specification:

1. Speed of each engine in revolutions per minute (RPM)
2. Speed of each primary electrical power source (generator or alternator)
3. Operating temperatures of each primary electrical primary source
4. Vibrational amplitudes and frequencies on each of the three axes for each primary electrical power source
5. Voltage output of primary electrical power source
6. Current output of primary electrical power source
7. Frequency of primary source power if ac
8. Voltage output of conversion equipment
9. Current output of conversion equipment
10. Frequency of conversion power if ac
11. Operating temperatures of each conversion power source
12. Output voltage of each emergency (or alternate) power source
13. Output current of each emergency (or alternate) power source
14. Frequency of emergency power if ac
15. Operating temperatures of each emergency power source
16. Current supplied to each load circuit bus
17. Outside air temperature
18. Equipment compartment and, if required, individual component temperatures
19. Altitude
20. Airspeed
21. Pressurization of battery installation.

8-7.2 ELECTRICAL POWER ANALYSIS

MIL-E-7016, *Electrical Load and Power Source Capacity Aircraft, Analysis of*, (Ref. 21) provides guidance for preparation and submittal of the electrical load analysis. Typical requirements include wiring diagrams showing cable designations and length; a description of the electrical system operation during normal, emergency, and abort procedures; the load analysis showing all power requirements on the subsystem under flight conditions, and the data, methods, and instrumentation pertaining to the contractor's flight and ground evaluations of the capabilities of the entire electrical subsystem.

8-7.3 ELECTRICAL AND ELECTRONICS COOLING

Typical electrical and electronic cooling subsystem airworthiness and qualification requirements are to substantiate that these subsystems perform in accordance with their specified requirements at the air vehicle and subsystem levels. The test objectives are to demonstrate that the electrical and electronic cooling subsystems are capable of dissipating the heat generated and maintaining the temperature environment necessary for reliable system operation. Typical methods used to provide thermal relief to electronic equipment include the use of ram air effects, blown ambient air, or environmentally conditioned air. Judicious arrangement of electronic units in the avionics bays can greatly reduce cooling requirements.

Measurements for electrical and electronics cooling testing include cooling air mass flow rates and temperatures. If air conditioning or external cooling air is provided to the electronic equipment, the testing should include operation of the equipment with simulated failure of the conditioning equipment and blowers. Outside air temperature, cockpit ambient temperature, and compartment temperatures should be recorded as time histories. Temperature data should be obtained with the equipment operating and not operating to demonstrate that actual operating and storage temperatures do not exceed the equipment design limits.

8-8 AVIONICS—COMMUNICATIONS

The purpose of airworthiness qualification testing is to demonstrate that the air vehicle communication subsystems meet the performance and functional interface requirements specified in the contract. Radio equipment used primarily to transmit and receive information by voice or code is classified herein as communication equipment. This includes high-frequency (HF), very high-frequency/ amplitude modulation (VHF/AM), very high-frequency/frequency modulation (VHF/FM), ultrahigh-frequency/amplitude modulation (UHF/AM) radio function equipment, interphone equipment, and related antennas. Also included are applicable digital controls, secure communications subsystems, and identification friend or foe (IFF) equipment. All avionics should be bench tested in accordance with approved test procedures before being installed in the test air vehicle. See Chapter 7 for additional guidance concerning component testing. Typically, the contractor should make use of commercially available specifications that satisfy performance criteria of applicable military specifications. If commercially available specifications and standards are unsatisfactory, the contractor should prepare bench, preflight, and flight test procedures. These test specifications should include pass/fail criteria. Also "fail soft" functionality of integrated avionic configurations should be required and demonstrated; see par. 8-18. Further, these specifications should be submitted to the PA for approval. In some cases the use of military specifications, military standards, or aeronautical design standards might be specified by the contract.

The airworthiness qualification test ground station should be validated by the contractor and accepted by the contracting agency.

The type of ground station antenna, antenna ground plane, and height of all test station antennas should be stipulated in the test plan prepared by the contractor. The characteristics of the ground station transmitters and receivers should be detailed, particularly the power output of the transmitters and the sensitivity of the receivers. For performance testing of communication equipment, it is desirable to use the same type of receiver/transmitter for the ground test station as is being tested in the air vehicle.

Communication subsystem tests should be conducted on a production air vehicle, preferably the first. The host air vehicle used for airworthiness qualification of the subsystem should be fully configured as specified in the contract and the air vehicle detail specification. The tests should demonstrate that the installation is satisfactory and that the communication subsystem meets or exceeds minimum performance requirements as specified in the contract. Information concerning the avionics airworthiness qualification may be found in MIL-I-8700, *Installation and Test of Electronic Equipment in Aircraft, General Specification for*, (Ref. 22) and consists of both ground and flight tests.

Antenna subsystems should be tested both on the ground and in flight. An antenna subsystem is the complete interconnection of the antenna, the transmission line (coaxial cable and connectors), radome, and all parts that serve to match, tune, isolate, erect, interconnect and protect the subsystem. For additional information, see MIL-STD-877, *Antenna Subsystem, Airborne, Criteria for Design and Location of*, (Ref. 23). From the standpoint of operational performance, the entire air vehicle is an essential portion of the subsystem.

Avionics—communications subsystem tests are further subdivided into external communications tests and internal communications tests in the two subparagraphs that follow. TEMPEST requirements apply to avionics—communications subsystems. These requirements deal with the control of classified data in order to prevent the exploitation of these data by enemy threat subsystems. TEMPEST testing is used to demonstrate the extent to which these data have been protected from being inadvertently disclosed to an enemy.

8-8.1 EXTERNAL COMMUNICATIONS

The objective of airworthiness qualification testing is to demonstrate that the air vehicle external communication subsystems perform all of the specified functions in the manner required by the contract. Typical qualification test objectives are to validate reliable and satisfactory two-way communications at the required distances on at least 10 frequencies spaced across each frequency band in question. Omnidirectional capability is typically required. The airworthiness qualification ground test program consists of a basic preflight test plus those tests necessary to establish that the avionic subsystem installation is satisfactory for airworthiness qualification flight tests and for the subsystem maintainability requirements. As discussed in par. 8-8, a ground test procedure including rejection criteria for each communication set should be submitted to the procuring activity for approval. The air vehicle to be tested should be fully configured as specified by the contract and the air vehicle detail specification.

Airworthiness qualification ground test activities and measurements typically include

1. Visual inspection to ensure proper installation
2. Avionics and antenna bonding checks; for information concerning this topic, see MIL-B-5087, *Bonding, Electrical, and Lightning Protection for Aerospace Systems*, (Ref. 24)
3. Cooling checks
4. Radio frequency (RF), output power, and voltage standing wave radio (VSWR) measurements
5. Transmitter modulation checks
6. Other functional checks to assure proper operation
7. Assurance of maintainability.

The airworthiness qualification flight testing measurements typically include evaluations of antenna patterns, communication performance at required distances, vibration characteristics, temperature, and cooling characteristics during all flight regimes.

Ground and flight cooling tests should be conducted to determine the maximum obtainable compartment temperatures for each communication set during service conditions. If air-conditioning or external cooling air is provided to avionic equipment, the testing should include operation of the avionics with simulated failures of the air- conditioning equipment and blowers. In addition, the outside air temperature (OAT), cockpit ambient temperature, and the compartment temperature should be recorded as a time history. The latter should be recorded during an acceptable duty cycle of the communication set with the air vehicle stationed on a runway and with the equipment turned on and then off. The temperature readings are necessary to establish that the actual operating and storage temperatures of the air vehicle do not exceed the design limits of the communications set under test. Worst-case storage and operating temperature data should be determined by extrapolation of measured data to the required ambient condition. Extrapolated data can then be compared with the design limits.

Ground measurements of RF output power and VSWR should be accomplished at 10 frequencies equally spaced over each band of interest, which should be the same frequencies used during flight testing. These measurements should be taken as closely as possible to both the transmitter and the antenna in order to obtain the power loss of the transmission line, the VSWR at the antenna element, and the VSWR of the entire antenna subsystem. It is necessary to measure the power on all of the flight test frequencies for comparison of the maximum operating range with actual power output of the transmitter. The test qualifications should stipulate the VSWR requirements.

Transmitter modulation should be checked for specific tolerances by using a normal voice into each microphone for each control station. End-to-end checks should be used in the secure modes of operation.

Both ground and flight operational tests should be performed to demonstrate reliable and satisfactory two-way communications on all flight test frequencies equally spaced across the bands. These should be the same frequencies used for ground test measurements and antenna tests. Communication quality and signal strength should be recorded during both types of tests. The same ground station should be used for both ground and flight communication tests. If the communication subsystem contains retransmission capabilities, the retransmission performance, quality, and levels also should be determined.

Performance flight tests of communication equipment should include measurements of communication quality and signal strength over a specified range and altitude to demonstrate that reliable two-way communication can be maintained to all points of azimuth. Quality and signal strength levels may be described as follows:

1. *Quality*. Unreadable; barely readable; readable, occasionally difficult; readable, no difficulty; perfectly readable.

2. *Signal Strength*. Faint to very weak; weak to fair; fair to good; good to medium strong; strong to extra strong. Speech intelligibility by using phonetically balanced monosyllabic word lists and other similar techniques also should be measured. The contractor should define the test approach to be used.

Performance flight tests of information friend or foe equipment should include verification by ground-based IFF equipment of proper replies to all modes of operation (1, 2, 3/A, C, and 4) over a specified range and altitude to demonstrate that reliable interrogations and replies can be maintained to all points of azimuth.

Both ground and flight testing are typically required for antenna subsystems. Ground tests of antenna subsystems are limited by reflections and ground effects. However, tests, such as VSWR, electrical bonding, mutual interference, impedance, and limited operational tests, are typically required. Each antenna should be checked, as a minimum, at the low, middle, and high end of its operational range for compliance with the specified performance requirements.

Antenna patterns may be measured by flying a cloverleaf flight plan or by flying a flat 360-deg flight turn (circular pattern). The advantage of the cloverleaf flight plan is the radial accuracy of the different headings flown during the test. The disadvantage is that a signal null might exist between two of the selected headings and would not be detected. By flying a circular pattern, a continuous monitoring of the antenna signal can be accomplished. If the circular pattern is used, the diameter must be small compared with the distance to the measuring station. It is also important that the center of the air vehicle circle be maintained over a known geographical point. The altitude above the ground must be as low as is necessary to maintain line-of-sight and good signal reception. For airborne transmitter antennas the signal-receiving and -measuring equipment may be installed at the ground station. However, for antennas to be used with receivers, it may be necessary to install the signal-receiving and -measuring equipment on the air vehicle if the power handling capability of the antenna is less than the power output of the transmitter. The most desirable and informative antenna patterns are those plotted from continuously recorded data for the entire 360-deg turn. Maximum-range should be conducted to determine the outbound and inbound range of the communication subsystems.

Vibratory tests should be conducted on each component of the communication subsystem during typical operating conditions—startup, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown—at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. Rotorcraft vibration generally extends to lower frequencies and to greater amplitude at these lower frequencies than the vibration of other aircraft. Therefore, test results should be obtained at these lower frequencies to ascertain that the subsystem is compatible with the rotorcraft.

8-8.2 INTERNAL COMMUNICATIONS

The internal communication subsystem airworthiness and typical qualification test objectives are intended to demonstrate that the internal communication subsystem allows the crew members to communicate with each other adequately.

TEMPEST requirements apply to internal communication of classified information; see subpar.7-10.5. These requirements deal with suppression of radiated signals that might emanate from electronic equipment in order to prevent the exploitation of these signals by enemy threat subsystems. TEMPEST testing is used to determine the extent to which these undesirable emanations are radiating have been eliminated from the subsystem

Measurements for internal communication include adequate switching capability for varying modes of operation, signal levels, and noise levels. These measurements are conducted by the flight test crew and typically are qualitative in nature. The data should demonstrate reliable and satisfactory operation of internal communication. If a subsystem is digital, the output signal to bus should also be checked.

8-9 AVIONICS—NAVIGATION

The purpose of this airworthiness qualification testing is to demonstrate that the air vehicle navigation equipment performs all of its functions as specified in the contract. The tests required to qualify a navigation subsystem are typically an extension of those performed on communication subsystems. As such, the airworthiness qualification test ground station for navigation subsystems is also validated. In many cases the tests can be accomplished concurrently because the equipment performs both communication and navigation functions. Generally, however, navigation tests will be more quantitative than communication tests. Also a greater variety of signal sources and types of output is used in airborne navigation. This results in a greater variation in test procedures than is found among communication subsystems. Three types of tests to demonstrate thoroughly the qualification of an airborne navigation subsystem are bench, preflight, and flight tests.

Navigation subsystem tests should be conducted on a production air vehicle, preferably the first. The test air vehicle should be completely provisioned with all avionic equipment. The tests should demonstrate that the installation is satisfactory and that the avionics meet or exceed minimum performance requirements as specified in the contract. Navigation subsystems should be bench tested in accordance with an approved test procedure before being installed in the test air vehicle. See Chapter 7 for additional guidance concerning component testing. The typical criteria for avionics airworthiness qualification tests—both ground and flight tests—may be found in MIL-I-8700 (Ref. 22). Ground testing should also include measurement of VSWR performance, and maintainability. Flight testing should include evaluation of antenna patterns, ranges, subsystem performances, vibration characteristics, and cooling characteristics throughout all flight regimes.

Objectively, the contractor should make use of commercially available specifications that the satisfy performance criteria of applicable military specifications. If commercially available specifications and standards are unsatisfactory, the contractor should prepare its own bench, preflight, production flight avionic airworthiness qualification test procedures. These test specifications should include pass/fail criteria and should be submitted to the procuring activity for approval. The electrical power required by each navigation subsystem should be measured to verify power consumption and thereby partially evaluate the air vehicle power generation and distribution subsystem. In some cases the contract might require full compliance with military specifications. Comply with the contract.

Ground tests of navigation antenna subsystems are limited by reflections and ground effects. However, tests, such as electrical bonding, impedance, and limited operational tests, should be accomplished. In the case of navigation antennas, such as an automatic direction finding (ADF) sense antenna, impedance measurements are necessary to verify that proper matching has been accomplished. Each antenna should be checked, as a minimum, at the low, middle, and high end of its operational range for compliance with the specified performance requirements.

Vibratory tests should be conducted on each component of the navigation subsystem during typical operating conditions—startup, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown—at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. Rotorcraft vibration generally extends to lower frequencies and to greater amplitude at these lower frequencies than the vibration of other aircraft. Therefore, test results should also be obtained at these lower frequencies to ascertain that the subsystem is compatible with the rotorcraft.

Ground and flight tests should be conducted to determine the maximum obtainable compartment temperatures for each navigation set during service conditions. If air-conditioning or external cooling air is provided to avionic equipment, the testing should include operation of the avionics with simulated failures of the air-conditioning equipment and blowers. In addition, the outside air temperature, cockpit ambient temperature, and the compartment temperature should be recorded as a time history. The latter should be recorded during an acceptable duty cycle of the navigation set with the air vehicle stationed on a runway and with the equipment turned on and then off. The temperature readings are necessary to establish that the actual operating and storage temperatures of the air vehicle do not exceed the design limits of the communications set under test. Worst-case storage and operating temperature data should be determined by extrapolation of measured data to the required ambient condition. Extrapolated data can then be compared with the design limits.

TEMPEST requirements apply to any form of navigation equipment that both transmit and receive. These requirements deal with suppression of radiated signals that might emanate from electronic equipment in order to prevent exploitation of these signals by enemy threat subsystems. TEMPEST testing is used to determine the extent to which these undesirable emanations are radiating from the subsystem.

The subparagraphs that follow discuss avionic navigation subsystem qualification requirements. Navigation subsystems are subdivided into inertial, Doppler, global positioning system (GPS), and broadcast, and hybrid. Navigation subsystems and systems should always be flight tested in three dimensions.

8-9.1 INERTIAL NAVIGATION SYSTEMS

The inertial navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform within the performance requirements of the specification.

Inertial navigation systems measure and integrate sensed accelerations of the air vehicle to derive position. Inertial systems must be initialized, i.e., they must be provided information about their starting location, each time power is applied in order to function.

Measurements for inertial navigation subsystems include position errors. Position error varies with distance traveled and time elapsed since initialization. These errors should be measured as a function of position and time to characterize subsystem performance.

TEMPEST is typically required for inertial systems if the inertial system is integrated into the weapon system in such a way that position data become classified and are transmitted over the data bus and between other air vehicles or ground stations.

8-9.2 DOPPLER NAVIGATION SYSTEMS

The Doppler navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform within the performance requirements of the specifications. Doppler navigation subsystems operate on the principle that a reflected radio signal frequency is altered if a velocity difference exists between the source of the signal and the surface from which it is reflected.

Doppler subsystem position errors tend to vary as a function of straight line distance from the initialization point to the position being measured. Doppler accuracy is also affected by the characteristics of the surface from which the Doppler return signal is being reflected. Test data should, therefore, include information on the terrain over which the air vehicle is flying during testing. These data should also include an estimate of sea state when flying over water.

8-9.3 GLOBAL POSITIONING SYSTEMS (GPS)

The GPS navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level. Additional test objectives are to substantiate the ability of the subsystem to acquire and track the GPS signals within the specific limits for specified navigational accuracy. The GPS operates on the principle that position can be very accurately calculated by receiving multiple signals from sources whose spatial, temporal, and signal characteristics are very accurately known. The signals being received by the host subsystem are radiated from multiple satellites. System errors tend to be affected by phenomena such as satellite positions, signal strength, and atmospheric conditions. The GPS accuracy is not driven by distance traveled or time of flight as is the case with the previous navigation subsystems.

8-9.4 BROADCAST NAVIGATION SYSTEMS

The airworthiness and typical test objectives of broadcast navigation subsystems are similar to those of communication subsystems. In many cases the tests can be accomplished concurrently because the equipment performs both communication and navigation functions. Generally, navigation tests should be more quantitative than communication tests. Also a greater variety of signal sources and types of outputs is used in airborne navigation. This might result in a greater variation in test procedures from subsystem to subsystem than is found among communication subsystems. Typically, three types of tests are required to demonstrate thoroughly the qualification of an airborne navigation system—bench, preflight, and flight. The bench tests are checks of the operational status of the subsystem components. The preflight tests are performed to assure proper installation. The ability of a subsystem to perform a particular mission can be determined only by flight test, which both simulates operational usage of the subsystem and allows collection of accurate performance data. Environmental tests also are required. Types of rotorcraft navigation subsystems to be considered include VHF omnidirectional range (VOR) receiving subsystems, low-frequency ADF subsystems, frequency modulation (FM) homing subsystems, gyromagnetic compass subsystems, tactical air navigation (TACAN) and distance-measuring equipment (DME), long-range navigation (LORAN), OMEGA (a low-frequency navigation subsystem used for long-range navigation), and instrument landing subsystems (ILS).

Typically, VOR qualification testing includes but is not limited to bearing accuracy (manual and automatic), to/from flag operation, warning flag operation, audio quality, and control. Bearing accuracy tests are typically performed with at least three simulated VOR bearings and on at least two frequencies in the 108.0- to 118.0-MHz range. Rotor modulation tests should be conducted over the entire operational range. Also electromagnetic interference and vulnerability testing should be conducted.

The ADF qualification testing includes but is not limited to sense antenna matching, reception using sense antennas, frequency accuracy, beat frequency oscillator operation, tune meter operation, manual loop operation aural null in manual mode, appropriate indication action in ADF mode. Flight testing typically includes ADF bearing accuracy with loop compensation, bearing accuracy without loop compensation, ADF performance flight test at range and altitude, and overstation passage accuracy. Bearing accuracy should be determined for relative bearings of 0 to 360 deg in steps not to exceed 30 deg. Range tests should be performed in all modes of the ADF set and on at least three different frequencies. Overstation passage tests should be run in the ADF mode. Also electromagnetic interference and vulnerability testing should be conducted.

Gyromagnetic and standby compass subsystem qualification testing typically includes but is not limited to operational checks and performance testing, compass swinging (compensation) procedures, synchronization, slaving, and warning flag operation. Compass swinging should be accomplished on a surveyed compass rose. See MIL-STD-765, *Compass Swinging, Aircraft, General Requirements for*, (Ref. 25) for additional information concerning establishing requirements.

Residual compass errors are typically recorded on compass calibration cards for display in the rotorcraft. Also electromagnetic interference and vulnerability testing should be conducted.

The TACAN/DME qualification testing includes but is not limited to bearing accuracy (azimuth angle), distance accuracy (slant range), maximum operating range, to/from indicator operation, course deviation indicator operation, audio quality, and control. Bearing and distance accuracy tests apply to TACAN operating in the air-to-ground mode and are typically performed with at least two TACAN ground stations. Distance accuracy tests are also performed in the air-to-air mode with two or more air vehicles equipped with TACAN equipment. Also electromagnetic interference and vulnerability testing should be conducted.

LORAN-C and OMEGA/VLF qualification testing includes but is not limited to the following:

1. A ground test to establish the functional performance of the receiver while installed in the air vehicle under normal conditions as well as in all degraded conditions under which the receiver is designed to operate

2. Electromagnetic interference and vulnerability testing prior to flight test

3. A flight test to characterize the performance of the receiver. This flight test should consist of a minimum of six separate way points geographically separate from each other and to the maximum extent possible over differing terrain. Each way point should be over a location that is established through aviation charts or other reliable means. At each way point the rotorcraft should establish a stationary hover. While maintaining the hover, the rotorcraft should execute a pedal turn, pausing every 30 deg as a minimum to record the displayed position as indicated by the receiver. These position records should be compared with the actual position of the air vehicle at each point and the data reduced in order to determine average error.

4. If formal instrument flight rules (IFR) certification of the LORAN-C subsystem is desired, demonstration of compliance with the requirements of Federal Aviation Administration (FAA) Advisory Circulars (ACs) 20-121, *Airworthiness Approval of Airborne LORAN-C Navigation Systems for Use in the US National Airspace System (NAS)*, (Ref. 26) and/or 20-130, *Airworthiness Approval of Multisensor Navigation Systems for Use in the US National Airspace System (NAS) and Alaska*, (Ref. 27) is required. If formal IFR certification of the OMEGA subsystem is desired, demonstration of compliance with the requirements of FAA ACs 20-101, *Airworthiness Approval of OMEGA/VLF Navigation Systems for the United States NAS and Alaska*, (Ref. 28) and/or 20-130 (Ref. 27) is required.

The ILS qualification testing includes but is not limited to localizer and glide slope position accuracy, warning flag operation, course deviation indicator operation, marker beacon operation, audio quality, and control. Also electromagnetic interference and vulnerability testing should be conducted.

8-9.5 HYBRID NAVIGATION SYSTEMS

Hybrid navigation subsystem airworthiness and qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level. Additional objectives are to substantiate subsystem reliability, navigational accuracy, and the ability of the subsystem to compensate for various abnormalities and errors. Hybrid subsystems combine two or more types of navigation subsystems to achieve better performance than separate subsystems are capable of, usually at combinations of lower cost and smaller size and decreased weight. Error characteristics of hybrid subsystems may be dependent on any combination of the following:

1. Time since initialization
2. Distance traveled
3. Atmospheric characteristics
4. Broadcast source characteristics including position relative to the air vehicle
5. Terrain conditions
6. Sea state if over water
7. Jamming and/or spoofing.

Test conditions must be specified differently, dependent upon the various subsystems that make up the hybrid subsystem. An advantage of hybrid subsystems is that they can usually be used in backup mode(s) when designed well. An example of this would be a Doppler/GPS subsystem that can operate in two backup modes: Doppler only when GPS is not available and GPS only when part or all of the Doppler subsystem is inoperable. Hybrid subsystems should be tested in each of their backup modes. The ADS-41, *Hybrid Navigation System Performance Flight Testing; Rotary-Wing Aircraft*, (Ref. 29) provides useful information concerning flight testing and evaluation of hybrid navigation subsystems.

8-10 CREW STATION DISPLAYS AND CONTROLS

The man/machine interface between crew station displays and controls is crucial to safe and proper subsystem operation. Improper design might adversely affect not only the operator's workload but also the safety characteristics of the subsystem. A properly designed crew station should consider the impact of human factors on crew efficiency and overall subsystem performance. The implementation and integration of mission equipment, controls and displays, lighting, and communications is instrumental to determining the efficiency and effectiveness of the overall weapon subsystem. For example, the lethality of a weapon may not be important if it cannot be delivered in a timely manner by the crew. The following paragraphs discuss specific aspects of these interfaces. (Also see subpar. 6-3.3.)

8-10.1 FLIGHT DISPLAYS

The airworthiness and typical qualification test objectives of the flight display subsystem are to substantiate that the flight displays satisfy all man/machine and environmental interface and performance requirements for safe operation during all required missions. The factors that establish flight-critical instrumentation allow the pilot to maintain control of the air vehicle safely during all situations. These include timing latency in the displays and integration of these displays within the cockpit. For example, requiring the pilot to move his head to operate essential equipment may cause pilot disorientation during operation under instrument meteorological conditions. Heads-up displays are an example of flight displays that usually contain flight-critical information. Flight-critical information usually includes, as a minimum, such information as air vehicle attitude, airspeed, and direction of flight.

Assessment of flight displays are primarily qualitative as to their functionality. In addition to the man/machine interface requirements, flight instruments are typically qualified as part of the various subsystems. Also electromagnetic interference requirements should be satisfied.

Par. 6-10 provides information on the use of modeling and simulation techniques to evaluate instrumentation characteristics.

8-10.2 FLIGHT CONTROLS

The flight controls subsystem airworthiness and typical qualification test objectives are to demonstrate that the air vehicle can be safely operated throughout its designated flight envelope. Human factors, such as control position extremes, location relative to pilot position, and flight controls switch locations and functions, should be evaluated.

Measurements for flight controls subsystems include the force required to activate the controls, the degree of feedback provided to the operator, and the maximum actuator rate at various load conditions. These measurements are generally obtained in conjunction with handling qualities testing.

Subpar. 6-3.3 provides information on the use of modeling and simulation techniques that may be used to evaluate flight controls.

8-10.3 COCKPIT AND INSTRUMENT LIGHTING

The cockpit and instrument lighting subsystem airworthiness and typical qualification test objectives are to demonstrate that the air vehicle and subsystems can be safely and effectively operated during night missions and with and without night aiding devices.

Measurements for cockpit and instrument lighting subsystems include brightness measurements and the degree to which brightness may be controlled and adjusted.

Subpar. 6-4.8 provides information regarding test setup and measurement.

ADS-23, *Lighting, Aircraft, Interior, AN/AVS-6 Aviators Night Vision Imaging System Compatibility*, (Ref. 30) provides relevant information concerning night vision goggle compatibility testing. Items to be verified include

1. Spectral radiant flux
2. Uniformity and balance
3. Brightness ratio
4. Dimming control
5. Veiling glare
6. Halo effect
7. Spectral reflections
8. Mode select switching
9. Priority of notice
10. Aircrew station signals
11. Internal surfaces and decals
12. Internal reflections
13. Power.

8-10.4 ELECTRONIC NETWORKS

The electronic network subsystem airworthiness and typical qualification test objectives substantiate that electronic-data-bus-controlled subsystems satisfy specification requirements and can be adequately controlled and operated.

Electronic networks provide a means for digital communications among various air vehicle subsystems. MIL-STD-1553, *Aircraft Internal Time Division Command/Response Multiplex Data Bus*, (Ref. 31) provides useful information for the data bus lines and interface electronic equipment. High-speed data buses should also be considered. MIL-HDBK-1553, *Multiplex Application Handbook*, (Ref. 32) provides useful information relevant to MIL-STD-1553 (Ref. 31) subsystems. Information concerning establishing interface requirements for interconnection and stores on air vehicles is contained in MIL-STD-1760, *Aircraft/Store Electrical Interconnection System*, (Ref. 33). Society of Automotive Engineers AS 4115, *Data Bus Systems Plan*, (Ref. 34) provides additional requirements for data bus testing.

Network control is a function of bus loading and latency. Data latency refers to the fact that a finite amount of time is required to transfer digital information from its source to its destination. The amount of time required is a function of the loading on the bus, i.e., the amount of bus traffic activity. Data latency results when the data reaching their destination is no longer valid or representative of the state of the system. Data latency effects may be modeled through simulations, such as time step simulations, to determine the latency effects on overall system performance.

Measurements for electronic network subsystems include but are not limited to data transfer and error rates and latency. These parameters are measured through the use of bus monitors while functioning all subsystems in an operational representative environment and duty cycle.

8-10.5 VOICE INTERACTIVE SUBSYSTEMS

The voice interactive subsystem airworthiness and typical qualification test objectives are to substantiate that the voice interactive system is capable of performing its intended function with all typical users.

Voice interactive systems provide the capability for the crew to control certain functions by issuing voice commands. This technique has the potential to reduce the crew's workload greatly. The critical characteristic of a voice interactive system is the capability to repeat consistently and accurately the appropriate response given a variety of individuals commanding the response.

Measurements for voice interactive subsystems include the size of the vocabulary of the system and the accuracy with which the subsystem is able to accept voice commands. In addition, the ability of the system to adapt to the voices of the total population of potential crew members should be evaluated.

8-10.6 MISSION EQUIPMENT PACKAGE COCKPIT INTEGRATION

The mission equipment package cockpit integration airworthiness and typical qualification test objectives are to demonstrate that all mission equipment has been integrated as needed to meet or exceed performance and interface requirements.

Measurements for mission equipment package cockpit integration is often qualitative in nature. A key item of interest is, "Can the crew member easily and consistently use a subsystem when required during all phases of operation?".

8-10.7 VISIBILITY

Aircrew visibility performance requirements should be provided in the air vehicle specification. Aircrew visibility, especially over the nose of the air vehicle, should not be restricted by the location of controls, consoles, and instrument panels. Also visibility should not be restricted by mounting and reinforcing strips that might be used to divide transparent areas. (See MIL-STD-850, *Aircrew Station Vision Requirements for* Military *Aircraft,* (Ref. 35) for additional information and guidance.)

Aitoff plots are a means of depicting the field of view from an air vehicle crew station. The plot depicts the limits of the field of view (in degrees from design eye position), and it is plotted onto a spherical plot. The contractor should demonstrate that the minimum angles of unobstructed vision illustrated in Fig. 8-2 and Fig. 8-3 are available to the pilot from the design eye position.

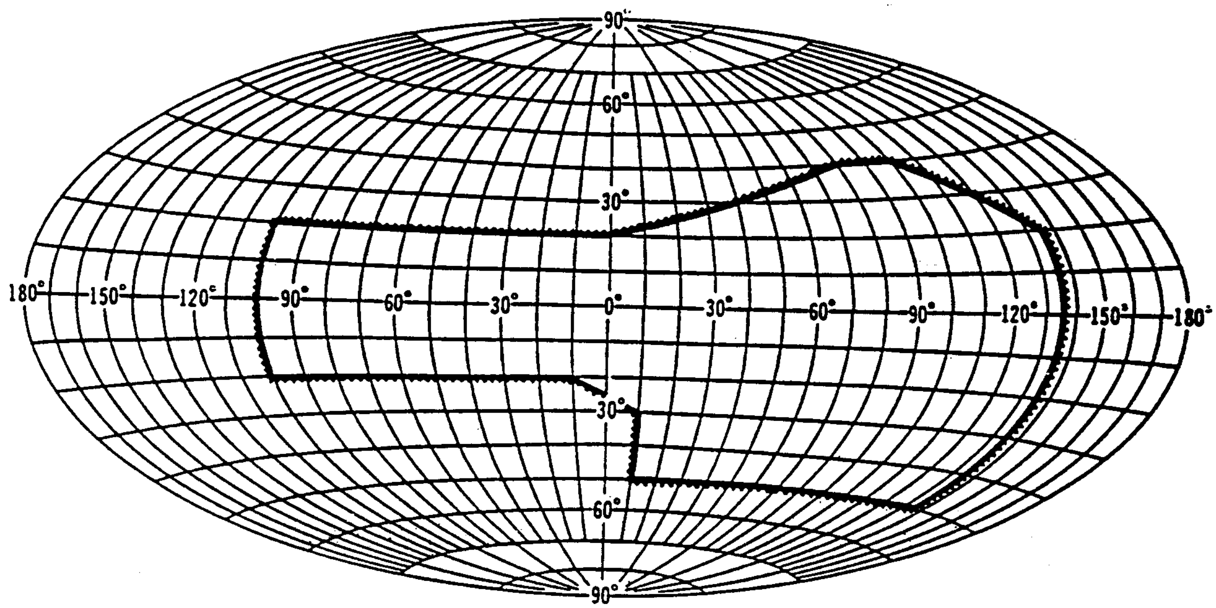

Figure 8-2 Side-by-side Helicopter Vision Plot

8-10.8 FLIGHT CREW VISIONICS

The flight crew visionics airworthiness and typical qualification test objectives are to demonstrate that the air vehicle can be safely operated using the visionics systems.

Targeting forward looking infrared (FLIR) subsystems have been adapted to provide the flight crew with visionics capability. The FLIR subsystem provides a visual representation of the thermal scene in front of the air vehicle. Such subsystems include helmet-mounted displays and imaging sensor slewing capability slaved to helmet motion. Human factors considerations and counter-countermeasures should be carefully assessed due to the critical nature of the man/machine interfaces involved in night pilotage by means of a visionics system. Slew rates of the helmet display and visual presentation of the visionics scene that is displayed to the pilot in relation to the real-world conditions are critical human factors concerns that relate to man-in-the-loop safe operation of the air vehicle.

Measurements for flight crew visionics include range and field-of-view capability of the subsystem and the degree to which the flight crew is able to perform the mission at night. Other considerations that determine mission performance capability is the subsystem image resolution contrast and the accuracy of the helmet position tracking.

8-10.9 PROPULSION CONTROLS

The propulsion controls airworthiness and typical qualification test objectives are to substantiate that the propulsion subsystem can be adequately controlled throughout the flight envelope. Propulsion control may be accomplished through the use of analog controls or digital controls. Digital control systems require qualification of the propulsion control system as well as qualification of the

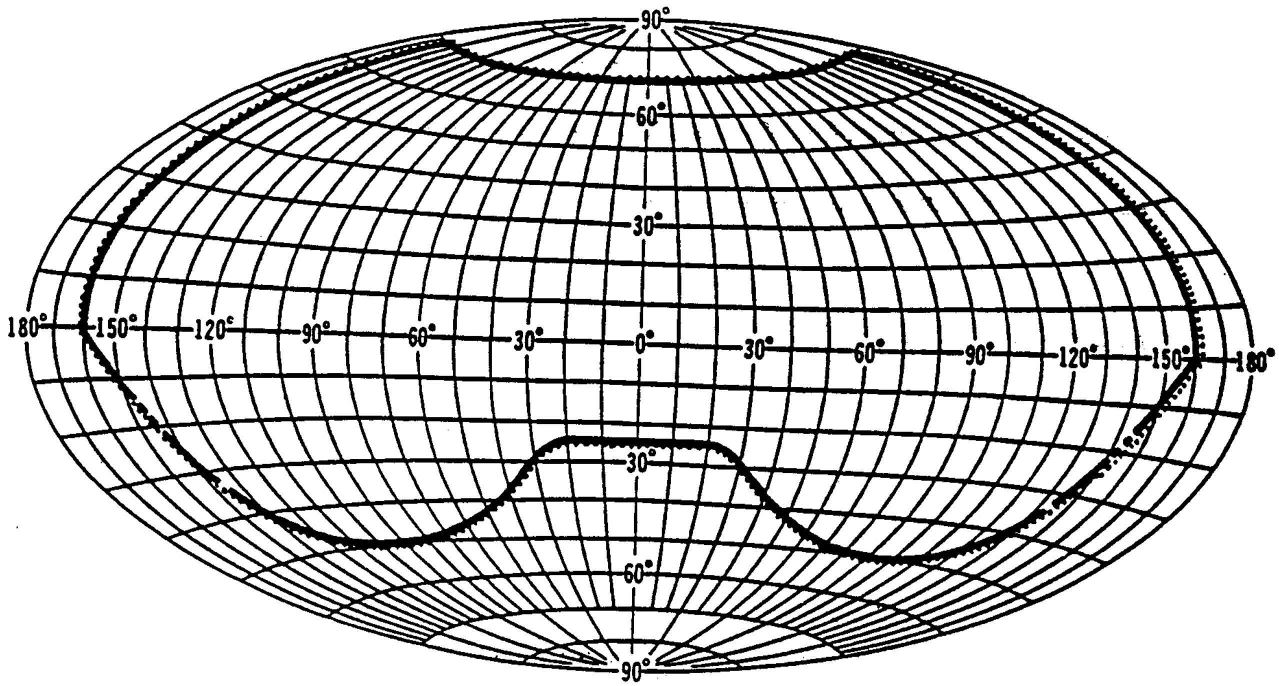

Figure 8-3 Single Pilot and Tandem Pilot Helicopter Vision Plot

software. Changes to the control software may also require requalification of the propulsion system. Qualification requirements increase as the authority of control increases. (See subpar. 6-4.5.4 for additional information.)

Measurements for propulsion controls include the force and response time necessary to accomplish propulsion control functions. These measurements should be taken during maneuvers and at the environmental conditions that represent the total flight envelope as closely as possible.

8-11 CREW STATION EQUIPMENT AND FURNISHINGS

The purpose of crew station equipment and furnishings airworthiness qualification testing is to demonstrate that all performance requirements of the air vehicle detail specification have been met and also that the crew can accomplish all functions necessary for the assigned missions. These qualification tests should also demonstrate the adequacy of personnel accommodations. A female aircrew in the 5th percentile in seated height and reach and a male aircrew in the 99th percentile in seated height and reach (Ref. 36) wearing the worst-case equipment and clothing—normally body armor and arctic clothing—should be able to perform all required functions when seated at each normal flight station with shoulder harness and seat belt fastened. See Chapter 6 for additional information and guidance.

MIL-STD-850 (Ref. 35) should be used for information concerning specifying aircrew station vision performance requirements for Army air vehicles. The particular air vehicles and mission requirements might necessitate external vision angles greater than those defined in MIL-STD-850 (Ref. 35) due to approaches over critical barriers, confined autorotations, etc. If greater angles are needed, they should be stated in the requirements portion of the contract. See subpar. 8-10.7 for additional information and guidance. The noise within the crew compartments should not exceed the maximum allowable performance defined in MIL-STD-1294, *Acoustical Noise Limits in Helicopters*, (Ref. 37) and MIL-A-8806, *Acoustical Noise Level in Aircraft, General Specification for*, (Ref. 38), as applicable. MIL-STD-1474, *Noise Limits for Military Materiel (Metric)*, (Ref. 39) also contains useful information concerning noise limits.

Evaluation of the seating and furnishings of the air vehicle should be accomplished insofar as is possible through detailed electronic mock-up evaluation; see Chapter 6. Satisfaction of all structural performance requirements should be demonstrated through engineering tests that involve stress analysis, laboratory test (shake table, etc.), and any destructive testing that might be needed. Further considerations to be evaluated are

1. Escape provisions
2. Comfort features
3. Restraint subsystem
4. Adjustment features
5. Passenger accommodations as they vary from pilot and crew accommodations
6. Protective armor, if applicable
7. NBC protection
8. Supplemental oxygen
9. Variable crew-mounted mission/survival equipment.

The crew seat subsystem should provide survivability from crash and ballistic threats. A variable energy attenuation feature should be incorporated to provide discrete adjustment for the Army aviator. Useful information may be found in MIL-S-58095, *Seat System, Crash-Resistance, Nonejection, Aircrew, General Specification for*, (Ref. 40). Additional information can be found in MIL-S-85510, *Seats Helicopter Cabin, Crashworthy, General Specifications for*, (Ref. 41). Protective armor should satisfy the requirements of MIL-STD-1288, *Aircrew Protection Requirements Nonnuclear Weapon Threat*, (Ref. 42). This is a military-specific requirement; however, a waiver is needed to cite this standard in a contract. Specific performance criteria should be included in the statement of work and specification. Unless otherwise specified by the PA, the seats for other aircraft should satisfy the requirements stated in Sections 25.561, 25.562, and 25.785 of Title 14, Code of Federal Regulations, Part 25, *Airworthiness Standards: Transport Category Airplanes*, (Ref. 43). Emergency escape and rescue design features should be tested and demonstrated. The PA should require emergency escape and rescue design criteria as specified in Technical Report (TR) 89-D-22A, *Aircraft Crash Survival Design Guide, Vol. 1, Design Criteria and Checklist*, (Ref. 44). However, for off-the-shelf, nondevelopmental aircraft the PA may be willing to accept aircraft and emergency escape and rescue design features that satisfy Title 14, Code of Federal Regulations, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic, and Commuter Category Airplanes*, (Ref. 45); Part 25, *Airworthiness Standards: Transport Category Airplanes*, (Ref. 43); 14 CFR, Part 27, *Airworthiness Standards: Normal Category Rotorcraft*, (Ref. 46); and 14 CFR, Part 29, *Airworthiness Standards: Transport Category Rotorcraft*, (Ref. 47), as applicable to the type of air vehicle. All contractually required emergency escape and rescue design features should be demonstrated or tested. Satisfactory ingress and egress for crew members should be demonstrated. There should be minimum difficulty of movement and probability of damage to or fouling of equipment, clothing, etc. Doors and hatches should be tested. The possibility of damage or fouling of the equipment should be demonstrated to be remote. Personnel participating should wear the heaviest clothing and carry the maximum equipment consistent with the mission. Also the evacuation provisions that follow should be tested or demonstrated:

1. Simplicity (simplest escape mode consistent with safety and effectiveness)
2. Cutaway areas clearly marked
3. Evacuation aids, such as adequate handholds
4. Quick-opening doors and hatches, easily operated
5. Doors and hatches operable with either hand with no more than two distinct and different motions
6. Adequate survival equipment provided
7. Easy breakaway of cockpit and aircrew connections.

8-11.1 AVIATION LIFE SUPPORT EQUIPMENT (ALSE)

The US Army makes use of a variety of specialized ALSE such as nuclear biological, and chemical (NBC) filtration systems; chemical and biological (CB) protective masks; CB protective clothing; laser eye protection; personal armor; air bags; restraint subsystems; survival vests; personal weapons; water survival equipment; oxygen subsystem; helmets; and helmet visors for its personnel and air vehicles. The oxygen subsystem and the helmet subsystem are discussed in the subparagraphs that follow.

8-11.1.1 Oxygen System

An oxygen subsystem might be needed for high-altitude search and rescue missions, use in an NBC environment, or similar missions utilizing air vehicles with unpressurized cabins. See subpar. 8-11.5 for other ALSE considerations.

Typically, US Army oxygen subsystems are of the pressurized bottle (gaseous) type. As a minimum, oxygen-breathing provisions should be provided for the pilot and copilot positions. The PA should specify whether additional provisions might be needed for transport-type rotorcraft. The PA should require that the air vehicle contractor (AC) qualify the oxygen subsystem and pressurized bottles (if any). The bottles usually are wrapped with wire or another suitable material to help prevent and contain an explosion. The oxygen subsystem should satisfy the applicable performance requirements of US Air Force Guide Specification (AFGS) - 87226, *Oxygen Systems, Aircraft, General Specification for,* (Ref. 48). Also MIL-D-8683, *Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for,* (Ref. 49) contains useful information concerning defining performance and validation requirements for oxygen subsystems. Onboard oxygen subsystems that satisfy the requirements of MIL-D-85520, *Design and Installation of Onboard Oxygen Generating Systems in Aircraft, General Specification for,* (Ref. 50) have been successfully investigated and demonstrated on Army rotorcraft.

Basically, onboard oxygen-generating subsystems use filtered engine bleed air as an oxygen source. However, some engines do not have sufficient bleed air to satisfy this function. Many (but not all) US Army aircraft operate at higher altitudes and have pressurized cockpits. These aircraft should have an integrated gaseous oxygen subsystem that fulfills the supplemental oxygen requirements of Title 14, Code of Federal Regulations, Part 91, *General Operating and Flight Rules*, (Ref. 51). Subsystem outlets should be located at all seat locations including the toilet compartment. Demand-type, quick-donning oxygen masks compatible with the selected headset and meeting Technical Standard Order (TSO) 78, *Crew Member Demand Mask Oxygen*, (Ref. 52) and regulators meeting TSO-89, *Oxygen, Regulator Demand*, (Ref. 53) have typically been installed, one each for the pilot and copilot within arms reach. Passenger masks should be furnished at all other outlets. In the event of cabin depressurization, the oxygen subsystem capacity should be sufficient for the crew and all passengers to permit an emergency descent (15-min minimum required) from the highest Federal Aviation Administration (FAA) certifiable altitude to 3960 mm (13,000 ft) (or below). In addition, sufficient oxygen should be available to permit the pilot and copilot to breathe normal demand oxygen during the return flight.

Typically, qualification test objectives are to substantiate that the oxygen supply equipment meets specified performance requirements, satisfies the physiological needs of the crew and passengers for all expected operations, subsystem does not leak, pressure regulation and flow at each station are adequate, cleanliness of the subsystem is adequate, safety relief subsystems are available and fully functional, and retention mechanisms are structurally adequate. Specific requirements should be specified in the air vehicle specification and Airworthiness Qualification Specifications.

8.11.1.2 Helmets

Critical characteristics of helmet subsystems include but are not limited to weight and center of gravity location; adequate impact and noise protection; and compatibility with chemical and biological protective masks, laser protective shields, night vision goggles, the optic and helmet sight subsystem, and heads-up display subsystems. The PA usually requires use of the HGU56/P helmet. Typical qualification testing should include form, fit, and function testing, which includes human factors evaluations, vision plots, impact tests, proper alignment, validation of weight and center of gravity location, validation of adequate noise attenuation, adequacy of laser protection, and compatibility with other ALSE equipment. Measurements for helmets include mass characteristics, comfort, and degree of head protection provided by the helmet. See subpars. 8-11.2 and 8-11.5 for additional human factors and ALSE considerations.

8-11.2 HUMAN FACTORS

Human factors performance and validation requirements should be clearly specified in the air vehicle and airworthiness substantiation specifications. Ultimately, it is the contractor who is totally responsible for design and for meeting specified performance. The contractor's integrated system engineering process should address human engineering design criteria, principles and practices to achieve mission success and allow safe, reliable, and effective performance by operator, maintainer, and support personnel. Validation of human factors requirements is typically accomplished by human factors analysis, visibility plots, anthropometrics, and analysis of control locations. Virtual prototyping, etc., can be used as an alternative to nonfunctional mock-ups. ADS-30, *Human Engineering Requirements for Measurement* *of Operator Workload*, (Ref. 54) provides useful information for measurement of operator workload; however, it does not include the performance requirements. The contractor can develop and propose other means as needed to demonstrate compliance.

8-11.3 CREW STATION CRASHWORTHINESS

Crashworthiness encompasses all design features and characteristics intended to ensure crew protection in the event of a crash. Crashworthy seats provide protection to the crew member by absorbing energy. Typically, crew members are retained in their seats by a five point restraint belt system. Assemblies and components located within the crew station should be adequately retained during a crash to avoid their becoming projectiles. Helmets should be capable of withstanding specified impacts. Also devices such as air bags and the inflatable body and head restraint subsystem (IBAHRS) have been investigated. The IBAHRS is a crash-activated inflatable restraint subsystem. Also crew station equipment, seats, etc., should be adequately retained to minimize the potential for injury. Adequate clearance should be provided to avoid head and body injuries during sudden stops. Provisions and procedures for evacuation provide a means to minimize the effects of a crash. The adequacy of provisions and procedures for evacuation should be demonstrated.

8-11.4 FLIGHT DATA RECORDER

The flight data recorder airworthiness and typical qualification test objectives are to demonstrate that the subsystem reliably records specified parameters and is capable of withstanding crash conditions, such as those associated with deceleration forces and extreme temperature. The flight data recorder should withstand specified vibrations including but not limited to gunfire-related vibrations. Embedded software should be verified and validated. Adequate reliability and maintainability should be demonstrated. Measurements for flight data recorders include the parameters recorded, the accuracy of the data, and the total data-recording capacity. Typical parameters to be recorded are altitude, airspeed, pitch, roll, yaw, pitch rates, roll rates, yaw rates, rotor rpm, engine torque, and control positions. However, it is feasible to monitor a much larger number of parameters. The specification should define what parameters are to be recorded. Typically, at least a one-hour capacity should be provided for air vehicle parameters. Also crew member voice recording of not less than 30 min with overwrite capability should be provided.

8-11.5 ENVIRONMENTAL CONTROL

Cockpit and cabin climatic conditions may be controlled by a variety of cooling, heating, and filtration methods. However, operation within a nuclear, biological, and chemical environment requires specialized equipment. The NBC agents should either be kept out of the cockpit or the crew should wear protective clothing. Typically, protective clothing has been used to provide the necessary protection; however, this clothing tends to be uncomfortable and cannot be donned in flight. The US Army has been investigating and developing an aircrew microclimate conditioning subsystem as protection against heat stress when operating with NBC protective clothing. Its purpose is to regulate body core temperature. Also a cockpit overpressurization system might be used to help keep NBC contaminants out of the cockpit. The overpressurization subsystem should have the capacity to compensate for various forms of cockpit leakage.

Airworthiness and qualification test objectives typically are to demonstrate adequate space, power, weight, body core temperature, filtration, compatibility with other equipment, and a variety of human factors considerations.

Cabin heating, ventilating, and air-conditioning subsystems should satisfy the performance requirements of the rotorcraft detail specification. Information concerning ground and flight demonstrations can be found in MIL-H-18325, *Heating and Ventilating Systems, Aircraft, General Specification for*, (Ref. 55) and MIL-T-18606, *Test Procedures for Aircraft Environmental Systems*, (Ref. 56).

A crew environmental survey should be conducted. The objectives of this survey are to verify that the crew station environmental control subsystem (ECS) is adequate to control the cabin environment and also to assure minimum human performance degradation within the operating environment and mission flight profile of the rotorcraft. Typically, this is demonstrated by climatic hangar, ground, and flight tests, as appropriate. The suitability of the crew station environment should be verified under the extremes of the projected mission environment. Tests should be structured to give quantitative results whenever possible. Environmental parameters for crew stations are

1. Crew station surface and ambient temperature distribution
2. Airflow velocity, particularly at each passenger station
3. Air supply toxicity and contamination
4. Emergency smoke removal
5. Temperature and airflow measurement relative to defogging and deicing of crew station windshield and window areas
6. Wet-bulb temperature
7. Solar radiation black globe temperature
8. Dry-bulb temperature.

Items 6, 7, and 8 should be used to determine wet-bulb globe temperature (WBGT), which is the heat stress index preferred by the Army. The wet-bulb temperature is measured using only ambient convection for evaporation, and the dry-bulb temperature is measured with a shaded thermometer. The solar radiation black globe thermometer measures the temperature at the center of a 152-mm (6-in.) diameter copper sphere whose exterior surface has been painted flat black. Relevant information can be found in TB MED No. 507, *Occupational and Environmental Health Prevention, Treatment, and Control of Heat Injury*, (Ref. 57).

Climatic hangar tests of the rotorcraft crew compartment are conducted to determine the performance compliance of each environmental subsystem. Normal and extreme temperature ranges are evaluated at static sea-level conditions. Climatic conditions, including varying humidity levels, can be simulated at a temperature range of from –54° to 71°C (–65° to 160°F). Heavy and/or freezing rain can be simulated at the required temperature conditions to evaluate transparent area anti-icing, defrosting, defogging, and rain removal subsystems. The operating capability of all ECS equipment can be demonstrated in the Eglin Air Force Base, FL, climatic hangar at the required 71°C (160°F).

Defogging and anti-icing performance and time constraints and validation requirements should be specified in the air vehicle specification and AQS. Information concerning these requirements can be found in MIL-T-5842, *Transparent Areas on Aircraft Surfaces (Windshield and Canopies), Rain-Removing and Washing Systems for Defrosting, Deicing, Defogging,* *General Specification for*, (Ref. 58) and MIL-T-18607, *Thermal and Fluid Anti-Icing Systems and Equipment, Aircraft External Surfaces*, (Ref. 59) including a visual inspection of the general construction and serviceability of the subsystem. Prior to the installation of an anti-icing or deicing, defrosting, or defogging subsystem, the contractor should submit for approval by the procuring activity a report showing a schematic drawing of the proposed subsystems and all design data necessary to comply with the requirements. These data should be detailed and should show the methods used to arrive at the necessary capacity of the subsystems, an explanation or description of subsystem operation, the heat requirements, and the heat distribution and airflow considering various altitudes, conditions of flight and ground operation, and effect of personnel comfort as outlined in MIL-T-5842 (Ref. 58). The report should also include items, such as an outline of the type and location of the instrumentation, conditions of test, and methods of tests. The instrumentation should be adequate to determine heat flows through the area, to determine the dew point at each transparent area, and to ensure that any area will not be overheated. The windshield anti-icing tests typically consist of laboratory and flight tests. Information concerning these tests can be found in MIL-T-5842 (Ref. 58). The quantity of heat applied to the windshield should be checked in flight to ensure that the quantity required (determined during laboratory tests) actually is available. An accepted method used to determine heat flow is to measure the inside and outside surface temperatures of the transparent area and measure the effect of the OAT. If the thermal properties of the transparent area are known, the heat flow can be determined. The accuracy of this method depends upon the available temperature differential, the external heat transfer coefficient, the ice accumulation rate, and whether steady state conditions have been attained. When ducting is used in any part of the subsystem, it should be tested for flow rate, temperature drop, pressure drop, and duct leakage, and the methods and instrumentation used by the contractor should be outlined.

Compliance with the ECS requirements should be established during flight test operations. Certain ground tests not normally conducted at the climatic hangar at Eglin Air Force Base, FL, also should be performed. Testing to determine compartment contamination levels should be performed during ground operation with all engines operating and the air vehicle stationed at a wind heading most likely to ingest contaminants into the cabin air supply. Air samples should be collected with the doors and windows of the air vehicle closed and also with the doors and windows open or removed (if applicable). The standards and exposure criteria applicable to toxic fumes testing by the US Army are basically governed by Title 29, Code of Federal Regulations, Part 1910.1000, Subpart Z, *Toxic and Hazardous Substances, Air Contaminants, Permissible Exposure Limits*, (Ref. 60) and Department of Defense Instruction (DoDI) 6055.1, *DoD Occupational Safety and Health Program*, (Ref. 61). The Army Surgeon General (TSG) can specify alternative standards in place of the Federal Code where special considerations must be applied due in part to the character of the military exposure environment, which can differ materially from exposures experienced by other populations. For example, the transient nature of some military exposures when combined with the uncertainties of the synergistic effects of simultaneous exposure to several gases can provide for entirely different criteria than specified in the Federal

Code. Finally, there is the category of standards and criteria that is not only unique to the military environment but is also singular to military populations, such as the standard for exposure to carbon monoxide. Typically, the Army Surgeon General makes the final decision regarding acceptability of concentrations of measured contaminants.

Flight test operations should be conducted to evaluate the controllability and the capacity of each environmental control subsystem throughout the flight spectrum during weapons firing. Specifically, airflow velocity conditions at cruise altitudes should be established. Temperature control response characteristics should be determined by manually setting the temperature control adjustment above and below the design setting. Air vehicles equipped with combustion heaters should be tested at flight and atmospheric conditions that require intermittent or low output heating operations. The fail-safe characteristics of the environmental control subsystem should be demonstrated by simulating failures of the power source supplied to the temperature or airflow controls. Heating, cooling, and ventilation subsystem capacity should be verified by operating the air vehicle at the most critical design speed and altitude.

Heating subsystem flight tests should be conducted at night to eliminate solar effects; also there should be minimum electrical and personnel loads within the compartment. Air-conditioning and ventilation (cooling) tests should be conducted in conditions as close as possible to those on the outside design curve in Fig. 8-4 with solar radiation and simulated maximum personnel and electrical heat loads. Subsystem performance tests should be conducted with a minimum of 75% of the passenger and crew accommodations occupied during cooling tests and a maximum of 10% of the passenger accommodations occupied during heating tests. Instrumentation should be provided to determine the temperature distribution within all occupied spaces of the air vehicle, all electronic equipment bays, and all compartments. Instrumentation should be provided to determine the velocity of flow in all occupied compartments under all conditions.

Tests should be conducted to demonstrate satisfactory flight procedures for smoke removal. Also an investigation of the cleanliness of the air supplied to the cabin should be made by collecting air samples in an evacuated container and analyzing the contents in a laboratory. Sufficient samples should be obtained to cover all flight conditions under which contamination might exist. The moisture content of the air in both crew and passenger compartments also should be determined. Test personnel should be equipped with suitable masks during this program. Tests should be conducted to demonstrate safe and satisfactory performance of the subsystem and equipment under the following conditions:

1. Climb
2. Descent
3. Level flight
4. Maneuvering flight
5. Hover (in-ground effect (IGE) and out-of-ground effect (OGE)).

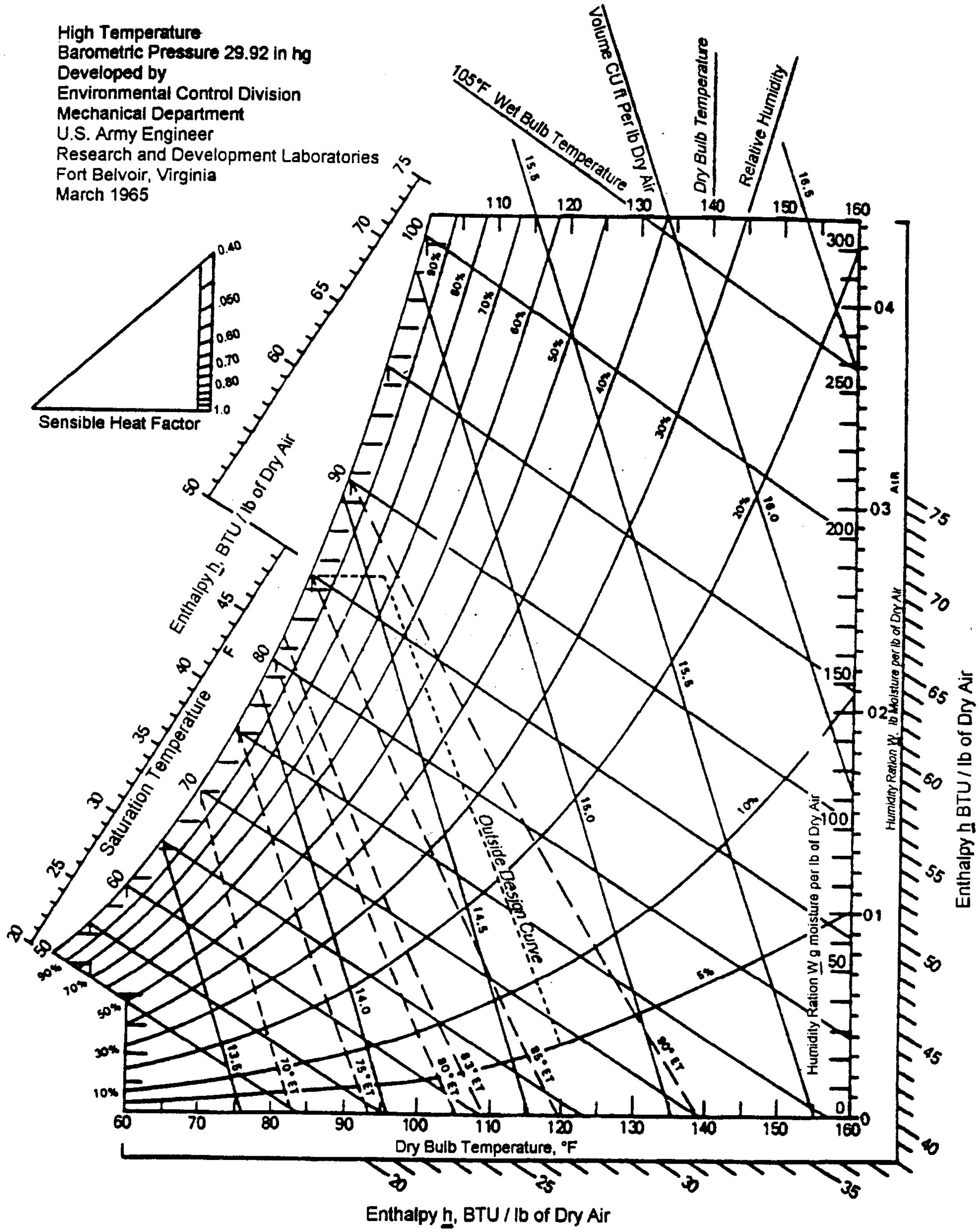

Fig. 8-4 U.S. Army Psychrometric Chart

Also contamination characteristics of the compartment air supply should be established during fueling, fuel jettison operations, and weapons firing. The air vehicle contractor usually prepares a plan in accordance with the CDRL. Also the air vehicle contractor usually collects air samples, performs analyses, and makes recommendations to the Government. Typically, air samples are analyzed for the following substances:

1. Ammonia (NH_3)
2. Carbon monoxide (CO)
3. Carbon dioxide (CO_2)
4. Nitric oxide (NO)
5. Nitrogen dioxide (NO_2)
6. Nitrogen (N_2)
7. Volatile organics.

The US Army Environmental Hygiene Agency is also capable of performing tests and analyzing the results. It has been recommended that air samples be compared to the more stringent of either the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL) (Ref. 60) or the emergency and continuous exposure guidance levels (EEGLs) contained in Vols. 4 and 5 of the *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants* prepared by the Committee on Toxicology (COT) of the National Research Council (Ref. 62). The COT EEGLs are recommended for use as criteria for the exposure of military personnel to toxic substances during military-unique situations or operations for which regulatory agencies have set no standard and typical 8-h per day workplace standards are not appropriate. The COT EEGL is a recommended exposure level at which Army personnel can continue to function and be unlikely to suffer irreversible effects.

The measurements that follow should be recorded during all ECS and ventilation subsystem tests:

1. Ground ambient dry-bulb temperature
2. Ground ambient wet-bulb temperature (ambient airflow)
3. Ground ambient globe temperature
4. Outside air temperature (in flight)
5. Dry-bulb temperature, pilot/copilot station at chest level
6. Wet-bulb temperature, pilot/copilot station at chest level
7. Globe temperature, pilot/copilot station at chest level
8. Air velocity, pilot/copilot station at foot level
9. Air velocity, pilot/copilot station at chest level
10. Air velocity, pilot/copilot station at head level
11. Temperatures of any surfaces in the crew station that feel hot to the touch from a cause other than solar radiation
12. Internal and external surface temperatures of the windshield measured at the top, middle, and bottom of the transparent area at centerline of pilot and copilot (deicing and defogging tests only)
13. Air velocity at each cooling or ventilation air discharge
14. Passenger compartment dry-bulb temperature
15. Passenger compartment wet-bulb temperature
16. Passenger compartment globe temperature.

8-11.6 TRANSPARENCY PROTECTION

Transparency protection is usually provided by a transparent wind screen. The wind screen should be capable of rain removal and should have adequate defog, defrost, and deice subsystems. Typically, heated air is used to clear the wind screen; however, electrically heated wind screen subsystems may also be used. The wind screen should have adequate clarity, freedom from distortion, abrasion resistance, and adequate field of vision and should provide ballistic and debris protection. The wind screen should be usable during both night and day. Also it should be usable with night vision goggles and related cockpit lighting. No material or construction should be used whose fracture would render the wind screen incapable of supporting the design limit load. For additional information refer to MIL-T-5842 (Ref. 58). Measurements for transparency protection include the degree of protection provided in terms of stopping specified types of projectiles and the optical characteristics of the transparency over its intended life.

8-12 PASSENGER FURNISHINGS

The passenger furnishings airworthiness and typical qualification test objectives are to substantiate that the passenger furnishings meet the requirements of the contract for safe operation during normal and emergency uses. Items that should be considered passenger furnishings include seats, restraints, ALSE, environmental control unit, communications, soundproofing, and fire-retardant materials. ALSE includes such varied items as first aid kits, flotation devices, oxygen systems, and other pilot survivability items.

Measurements for passenger furnishings include crash load attenuation provided by crew seats, acoustic attenuation of soundproofing, fire-retardant properties and placement of materials in the air vehicle, and capability of the environmental system to provide pilot comfort at the specified levels.

8-13 HOIST SUBSYSTEMS

Rescue and cargo hoist airworthiness and qualification tests should substantiate the load capacity and safety requirements for these subsystems. Data should be provided to demonstrate the capability of the hoists to operate throughout their intended flight envelope and at the required operating conditions. Specific requirements for rescue and cargo hoist qualification requirements are discussed in the subparagraphs that follow.

8-13.1 RESCUE HOIST

The rescue hoist airworthiness and typical qualification test objectives are to substantiate all of the various safety features as required by contract and also to demonstrate that the subsystem is capable of carrying the maximum rated load at 3 g's through a 60-deg cone angle. Also it should be demonstrated that the subsystem is not adversely affected by a specified electromagnetic field. The hoist should be capable of safely carrying the maximum rated load to the extremes of the applicable flight envelope. The demonstration should include operation of all control devices, antibacklash features, limit switches, and overload sensors used in the hoist subsystem. Quick-disconnect devices and cable cutters should be actuated at the most critical load conditions. Operating procedures defined in the operator's manual should be followed throughout the demonstration. The host rotorcraft and externally loaded rescue hoist should be flown at all conditions that are critical to strength, maneuverability, stability and control, and aeroelastic stability. Any other factors that are considered critical should also be demonstrated. The rescue hoist should also satisfy the various human factors performance requirements as specified in the contract.

Measurements include proof load, acceleration forces, quick-disconnect forces, and in-flight dynamic and aerodynamic forces.

8-13.2 CARGO HOIST

Airworthiness and qualification test objectives are to demonstrate that the subsystem can safely carry loads externally on the hoist to the extremes of the applicable flight envelope and also to demonstrate that the host rotorcraft is not adversely affected. The host rotorcraft and externally loaded cargo hoist should be flown at all conditions that are critical to strength, maneuverability, stability and control, and aeroelastic stability. Any other factors that are considered critical should also be demonstrated. The maximum hoist subsystem rated load is to be used for these tests unless a lesser load is more critical to dynamic stability.

The hoist subsystem should be demonstrated through a minimum of six operations at maximum rated capacity. The demonstrations are to cover all normal and emergency modes of operation, e.g., hydraulic, electrical, or manual. The hoist should be manipulated from each operator's station from which it can be operated.

A minimum of four load/speed combinations should be demonstrated to determine compliance with the rotorcraft detail specification. Speeds at minimum or zero load, 50%, 75%, and maximum rated load are typically used. The demonstration should include operation of all control devices, limit switches, and overload sensors used in the hoist subsystem. Quick-disconnect devices and cable cutters should be actuated at the most critical load conditions. Operating procedures defined in the operator's manual should be followed throughout the demonstration. Electroexplosive devices should be tested to validate adequate safety margins from inadvertent actuation; see subpars. 9-11.1 and 9-11.5.1.

Typically, the maximum rated load should be applied and the hoist installation tested at 2.5 g's throughout a 60-deg cone angle. Larger acceleration-related forces may be specified by the contract. Measurements include proof load, acceleration forces, quick-disconnect forces, and dynamic- and aerodynamic-related forces.

8-14 CARGO PROVISIONS

Typical internal cargo provisions include tie-downs, flooring, ramps, doors, winches, and cargo-handling rail-roller systems. External cargo provisions include cargo hooks and their associated hardware. Descriptions of internal and external cargo provisions and their airworthiness requirements are described in the subparagraphs that follow.

8-14.1 INTERNAL CARGO PROVISIONS

Typical qualification test objectives for internal cargo provisions are to confirm operational procedures and envelopes and assure subsystem compatibility. Proper operation of all tie-down fittings and devices should be demonstrated. Representative demonstration cargo should be made up and secured in the air vehicle using the procedures defined in the operator's manual. Particular emphasis should be placed on accessibility and ease of operation of tie-down provisions.

Qualification of individual components and subsystems, as required by their specifications, must have been completed before demonstration tests are begun. These tests, however, need not be repeated during the demonstration test. Strength test of attachment of cargo furnishings and fittings to the air vehicle structure should be completed prior to demonstration tests. Typically, these tests are accomplished by laboratory bench tests or on the static test air vehicle. Cargo tie-down provisions should be sufficient not only for flight but also for crash-landing conditions. Crashworthiness structural requirements are identified in the air vehicle specification or as emergency landing conditions in the FAA standards. Also it should be demonstrated that cargo-loading provisions maintain the air vehicle CG position within the approved limits and that CG movement associated with cargo airdrop is within limits.

Measurements for internal cargo provision include the capability to restrain the load in accordance with the air vehicle detail specification. A proof test of the cargo compartment floor to limit loads should be accomplished. Design limit loads, both distributed and concentrated, should be applied to walkways, treadways, and general cargo and passenger area floors. Also all conveyors and tracks installed in the air vehicle should be subjected to proof tests. Limit loads and concentrated loads should be applied, and the loads should be moved along the conveyor or track at maximum permissible speed. Proof tests also should be conducted at any other critical load/speed combination.

All cargo doors and ramps are typically demonstrated through six complete operations in the normal modes, i.e., manual, electrical, or hydraulic. Alternate modes or procedures to be followed in emergencies are typically demonstrated through one operation. Procedures contained within the operator’s manual should be followed. Doors and ramps that are used as cargoways during loading and unloading operations should be subjected to proof tests at limit loads.

Also all cargo doors and ramps intended for airborne operation should be demonstrated in flight. The outer limits of the operational flight envelope of the cargo door and ramp should be demonstrated as well as any other critical points within the envelope. The demonstration should cover all normal modes of operation and the emergency procedures. Doors and ramps that can be blown off or otherwise ejected or lost from the air vehicle in an emergency need not be included in this demonstration. However, it should be demonstrated that door or ramp separation from the air vehicle does not result in additional hazards. Additional hazards might result from a separated object or debris striking the tail rotor or in adverse aerodynamic loading from the change in the aerodynamic configuration. All control devices including limit switches and overload sensors should be demonstrated. Changes in host air vehicle control forces, yaw rates, etc., should be measured.

8-14.2 EXTERNAL CARGO PROVISIONS

Typically cargo hooks are used for external cargo. The cargo hook subsystems should be demonstrated with the rotorcraft in flight. Automatic and semiautomatic hook engagements of a load should be made. All release modes including normal, automatic touchdown, manual ground, and emergency should be shown. Emergency release should be demonstrated during turns at the maximum allowable bank angle and speed and while carrying maximum rated loads. These tests may be carried out jointly with the test of the hoist subsystem.

Relatch features are to be operated, and proper operation of safety or warning devices, such as unlatched load beam indicator lights, should be verified. The demonstration should follow the procedures in the operator's manual.

External cargo provisions should be adequate for use with aerial recovery subsystems, such as those typically designed for recovery of disabled rotorcraft. Also these same provisions should be adequate for transportability of other high-mass items, such as trucks and cannons. Usually, objectives of qualification are to demonstrate that externally carried loads can be safely lifted, transported from one location to another, and let down. As such, qualification is needed at both the subsystem and system levels. Qualification efforts should include structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, human factors, and functional analyses and testing. Airworthiness and crashworthiness of the host air vehicle should not be degraded. Typical measurements include weight, sling loads, aerodynamic forces, vibrations, and airspeed. Specific performance requirements should be specified in the contract. The US Army Natick Research, Development, and Engineering Center is the proponent for external and sling loads. Therefore, any requirements should be coordinated through that organization.

8-15 LAVATORIES AND GALLEYS

The lavatories and galleys airworthiness and typical qualification test objectives are to demonstrate that personnel can safely operate and maintain these subsystems. Safety-critical items for lavatories and galleys should be evaluated to ensure there are no sharp corners and/or edges to cause injuries if turbulence is encountered and to ensure that the temperatures of items in the galley can be maintained at a safe level.

Measurements for lavatories and galleys include potable water and waste tank capacity, temperature control of galley heating ovens and hot plates, and human factors concerns.

8-16 TARGETING, ARMAMENT, AND FIRE CONTROL SUBSYSTEMS

The major elements of targeting, armament, and fire control subsystems include sensors, trackers, range finders, guns, rockets, missiles, and the associated electronic equipment necessary for integration and control. Targeting subsystems are designed to provide the flight crew with the capability to detect, acquire, track, range, and designate tactical targets. Targeting subsystems should be safe. Information concerning laser safety can be found in MIL-STD-1425, *Safety Design Requirements for Military Laser and Associated Equipment*, (Ref. 63). Also see subpar. 7-11.1.

Targeting, armament, and fire control subsystem performance are affected by target characteristics that must be specified in order for subsystem performance requirements and measurements to be meaningful. Target characteristic include information such as

1. Target type, e.g., tank, wheeled vehicle, etc.
2. Target size
3. Target-to-background contrast for visual sensors
4. Target-to-background temperature difference for thermal imaging sensors
5. Target radar cross section for radar subsystems
6. Target motion, velocity, and acceleration in directions along and perpendicular to the line of sight of the sensor
7. Target countermeasure characteristics such as foliage, nets, degree of defilade, obscurants, and others.

In addition to target characteristics, armament and fire control subsystem performance is tied to atmospheric conditions, which must also be specified in order for subsystem performance requirements and measurements to be meaningful. These atmospheric conditions and parameters include

1. Ambient pressure and temperature
2. Visibility conditions
3. Atmospheric attenuation at the specified wavelength for the sensor
4. Humidity conditions
5. Precipitation conditions (rain, snow, and sleet)
6. Atmospheric scintillation effects.

ADS-20, *Armament/Fire Control System Survey*, (Ref. 64) contains information about verifying the safety and performance of each armament fire control subsystem by means of ground and flight survey testing. Ground surveys are needed to determine airworthiness. Ground and flight surveys can be used to determine development status prior to formal qualification. These surveys usually encompass installation, ground checkout, ground firing, and preflight and flight testing of armament and fire control systems in the air vehicle. Typically, the following are tested:

1. Missile subsystems
2. Aerial rocket subsystems
3. Turreted gun subsystems
4. Target acquisition and designation subsystems
5. Fire control subsystem integration
6. Boresighting subsystems.

8-16.1 SENSORS

Sensors types include television subsystems, radars, thermal imaging subsystems, optical subsystems, and radar frequency interferometers. Sensor subsystems enable the operator to search visually for and acquire targets for both day and night engagements that are beyond the normal human visual capability.

The sensor airworthiness and typical qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements.

Measurements for thermal imaging sensors include fields of view, modulation transfer function (MTF), system intensity transfer (SIT), minimum resolvable temperature (MRT) difference, optical or electronic noise, cross talk between detector elements, distortion, and noise equivalent temperature difference (NETD).

Measurements for television subsystems include fields of view, noise, automatic light control (ALC) performance, shading characteristics, screen blemishes, signal level, distortion, field-of-view alignment, and MTF.

Stabilization is a key parameter for both thermal imaging and television systems. The systems should be isolated from both rotor and airframe vibrations.

8-16.2 TRACKERS

Trackers allow for automatic maintenance of the sensor line of sight to the target regardless of the motion of the target or of the air vehicle within specified parameters.

The tracker airworthiness and typical qualification test objectives are to demonstrate that targets can be tracked throughout the required conditions.

Measurements for tracker qualification should include determination of the capability to track targets in various environmental conditions including clutter, obscurants, target multiplicity, and varying target spacing.

8-16.3 RANGE FINDERS

Range finders provide distance information between the target and the weapon platform. These data are used by the fire control computer to perform the fire control function. The airworthiness and typical qualification test objectives for range finders are the determination of performance parameters, such as maximum range capability, probability of single pulse detection, probability of single pulse false alarm, range finder accuracy, range finder resolution, and range precision.

The range finder airworthiness and typical qualification test objectives are to substantiate that the range finder accurately and consistently determines range under the specified conditions.

Measurements for range finders include output energy, interpulse period, pulse width, pulse-to-pulse time stability, pulse-to-pulse energy stability, beam divergence, and radiation outside the main beam. These measurements should be taken with various environmental conditions that include clutter, obscurants, target multiplicity, and varying target spacing.

8-16.4 ARMAMENT

Armament subsystem qualification is conducted to determine the ability of the weapon subsystem to satisfy performance requirements of the air vehicle and detail specifications. The armament subsystem should be configured as nearly as possible to the production installation. The test program should determine by measurements and demonstrations the following:

1. Accuracy

a. Subsystem boresighting accuracy and retetion

b. Round dispersion at the specified range(s)

c. Rocket and missile dispersion around target(s)

2. Arming and rearming time

3. Capability of operation under environmental stress from

a. Temperature

b. Salt fog

c. Sand and dust

d. Humidity

e. Rain

f. Vibration

g. Shock/bench handling shock

h. Blast overpressure

i. Icing

j. Fungus

k. Solar radiation

4. The effect of the subsystem on the environment such as

a. Toxic gases

b. Noise levels

c. Explosive atmosphere

5. System safety

a. Provisions for adequate safety devices for ground crew protection and in-flight operational safety

b. Jettison

c. Electromagnetic compatibility

d. Gun, rocket, and missile safe firing envelopes

e. Adequacy of armament inhibits, limits, and interrupts

6. Flight handling qualities and performance

7. Maintenance requirements and reliability.

Specific qualification tests that should be performed include but are not limited to the following:

1. Cockpit procedures testing, which includes switching, safety, and flight crew interactions

2. Subsystem controls, such as cockpit controls, switches, instruments, displays, and sights

3. Boresighting procedures should be demonstrated. Any special tools or devices required to accomplish boresighting should be used. Boresighting should be

rechecked periodically throughout the firing tests to determine the degree of boresight retention.

4. Procedures used to load and unload ammunition or stores should be demonstrated, as well as the safety procedures to be followed during the loading and unloading process. The time required to rearm should be determined and documented. Operational ground handling equipment should be used in the demonstration, and ground maintenance and troubleshooting procedures should be followed.

5. Armament firing tests should provide the following information:

a. Airframe response to pressure from the weapons and sonic energy pulses throughout the firing envelope of the weapons during both ground and flight operations

b. Recoil loads and airframe response to weapon rate of fire throughout the subsystem range of motion during both ground and flight operations

c. Cockpit noise levels

d. Electrical and hydraulic load on air vehicle subsystems from armament system operation

e. Gas accumulation in the cockpit, ingested into the engine, and in the vicinity of the weapon

f. Accuracy and boresight retention

g. Firing envelopes and clearances

h. Weapons debris does not degrade the air vehicle, tail rotor, engine, and externally mounted equipment.

6. Compatibility of the weapon subsystem within its anticipated environment, such as temperature-altitude, salt spray, vibration, dust, shock, blast, icing, and explosive atmosphere

7. Flash intensity tests to determine the effects on the crew, sensors, and cockpit lighting conditions should be assessed.

8. Clearance tests substantiating that there is no possibility of firing the weapons through the rotor path or propeller path in all possible weapon aiming and air vehicle flight conditions

9. “HERO” tests to demonstrate adequate safety margins from inadvertent detonation of electroexplosive devices.

Armament subsystem-level test objectives and measurements include determination of the following characteristics:

1. Turret or gun subsystem slew rates and position accuracy

2. External stores travel, slew rates, acceleration synchronization, and position accuracy with typical loads

3. Gun firing rates and ammunition belt loads.

MIL-H-8591, *Airborne Stores, Suspension Equipment and Aircraft-Store Interface (Carriage Phase); General Design Criteria for*, (Ref. 65) provides general structural and mechanical design criteria that can be used to establish performance requirements for airborne stores, suspension equipment, and their associated interfaces. A waiver is required to cite this specification. Provisions are included to promote cross-utilization and servicing capability among military air vehicles of all services of the Department of Defense and air vehicles of various NATO countries.

A program of static, dynamic, repeated load, environmental, wind tunnel, and other ground tests required for proof of structural and operational performance should be performed. Operational flight tests including carrier or shipboard suitability testing, if applicable, to demonstrate the structural and functional adequacy of the store should be performed.

8-16.5 FIRE CONTROL

The airworthiness and typical qualification test objectives for fire control subsystems include determination that the fire control subsystem provides the functions required for safe and effective operation of the armament subsystems.

The fire control subsystem provides the mechanism used to integrate all aspects related to target detection and to weapon subsystem aiming and firing. Typically, this function is provided by a fire control computer, which accepts information and control from the various fire control subsystems on the air vehicle and provides aiming, firing, and guidance information to the weapons.

Measurements for fire control subsystems include overall weapon firing accuracies in comparison to specified requirements. The accuracy measurements should include the data required to demonstrate the end-to-end compatibility of the weapons, sights, and targeting algorithms. These measurements should include recording of air vehicle position; weapons pointing data, such as azimuth, elevation, and range to target; and impact missed distances.

8-16.6 SENSOR FUSION

A sensor fusion subsystem is an integrated set of other subsystems that can be used to enhance targeting and piloting capabilities. Sensor fusion provides a means by which to combine target information automatically into the fusion processor from several sensors to determine whether or not an object is a target of interest. The objective is to provide increased target detection performance that would be available from any single sensor.

The airworthiness and typical qualification test objectives for sensor fusion include determination that system-level target detection performance requirements have been achieved as specified by the contract.

Measurements for sensor fusion include measurements and analysis of target detection probability and target false alarm rates. The analysis and measurements should take into account the target environment the subsystem is expected to encounter in actual operation. This includes target type, background conditions, and potential false targets in the scene. Technical performance testing of sensor fusion capabilities should be conducted on a controlled access range that has known surveyed targets. Environmental conditions including ambient light, temperature, humidity, and obscurant levels should be recorded.

8-16.7 SUBSYSTEM COUNTERMEASURE RESISTANCE

Sensor subsystems are susceptible to various countermeasure techniques intended to reduce their performance or in some cases destroy critical components and thereby render them ineffective. Countermeasure test requirements should be developed on the basis of the threats expected to be encountered by the fielded weapon system.

Countermeasures may be of the active or passive type. Active countermeasures include attempts to introduce intense sources of radiation into the sensor at the operating wavelength of the sensor. Tests and measurements should be made to determine the degree to which the sensor is able to operate either at specified performance levels or reduced levels in the presence of these countermeasure sources. The subsystem performance measurements are generally taken in a noncountermeasure environment, and the tests are repeated in a countermeasure environment to provide a direct comparison of the effectiveness of the specific countermeasure. In addition, measurements and assessments should be made of any damage to the equipment caused by the use of such sources. Of particular concern should be the protection of the operator from any potential injury caused by the use of the subsystem in a countermeasure threat environment.

Passive countermeasures include but are not limited to the use of decoys and techniques, such as camouflage, that make the target appear to be part of the clutter. Testing should be conducted at benign conditions (noncountermeasured) and with passive countermeasures to determine the effectiveness of the specific countermeasure against a given system or systems. Subsystem performance tests should be performed to assess the capability of the various sensors and any sensor fusion techniques to perform at their intended target detection probabilities in a passive countermeasure environment. The results will probably be classified.

8-17 SPECIAL MISSION AND NEW SUBSYSTEMS

Electronic countermeasure subsystems and electronic surveillance subsystems are examples of special mission and new subsystems. Electronic countermeasure subsystems are intended to reduce the performance of or defeat enemy electronic systems including communications and navigation equipment. Electronic countermeasure systems emit electronic radiation detrimental to the operation of enemy systems. Test measurements of such subsystems include power, frequency, and other characteristics of the emitted signals and comparing them with specification requirements. Passing criteria for these measurements are generally defined in terms of the amount of performance degradation to the targeted equipment caused by the countermeasure. The type of performance degradation and how that degradation can be determined are normally system dependent. It is also critical to assess the effects of such systems on other mission equipment installed on the test air vehicle and to determine any adverse impacts of the electronic countermeasure on friendly electronic systems.

8-17.1 ELECTRONIC/OPTICAL AREA SURVEILLANCE

The electronic/optical area surveillance airworthiness and typical qualification test objectives are to demonstrate that these subsystems perform to their required performance requirements and do not cause any adverse impacts to other installed subsystems. The demonstration should include not only substantiation of the performance capability of the subsystem being qualified but also performance monitoring of other subsystems to ensure their performance is not degraded. If the subsystem changes the exterior dimensions of the air vehicle, flight performance and handling qualities testing might be required to determine any changes caused by the installation of the electronic/optical subsystem. Other subsystems should also be monitored for potential electromagnetic interference.

Measurements for electronic area surveillance subsystems include frequency coverage, sensitivity, and data storage capacity. Measurements for optical area surveillance subsystems include field of view, resolution, and image capture and storage capability. The specific measurements for these subsystems and their pass criteria are usually subsystem dependent and should be specified by the procuring agency. These performance requirements and test results will probably be classified.

8-17.2 AERIAL DELIVERY SYSTEMS

An aerial delivery system is typically an airdrop subsystem, as compared with the cargo handling subsystem addressed in subpar. 8-14.1. Aerial delivery typically is not used with rotorcraft. Aerial delivery systems are usually palletized loads and involve the use of parachutes. Cargo is pushed or pulled from the aircraft. The US Army Natick Research, Development, and Engineering Center is responsible for qualification approval of air delivery hardware. The US Air Force normally accomplishes the in-flight demonstrations and qualification. All loads should be adequately restrained within the aircraft and should withstand all acceleration and crash-related loads specified for the aircraft. Typical objectives of qualification include the demonstrations that follow:

1. Specified aerial delivery loads can be installed in the specified type of aircraft.
2. Specified aerial delivery loads can be properly secured within the aircraft.
3. Tie-down provisions are adequate.
4. Aerial delivery loads and related tie-down provisions withstand all transportability-related loads.
5. Aerial delivery loads can be safely extracted from the aircraft.
6. Parachute loads are aerodynamically stable.
7. Rate of descent is adequate.
8. Aerial delivery loads are adequately cushioned for ground contact.

See MIL-STD-209, *Slinging and Tie-Down Provisions for Lifting and Tying Down Military Equipment*, (Ref. 66) for additional information. The contract should specify the actual performance requirements. Typical measurements include weight, size, clearance, rates, deployment loads, parachute loads, and impact loads.

8-17.3 ADDITIONAL WEAPONS

The additional weapons airworthiness and typical qualification test objectives are similar to those described in par. 8-16 for targeting, armament, and fire control subsystems. Flight performance and handling qualities testing may be required for additional weapons subsystems that are externally mounted. Test data should also be provided to demonstrate that the additional weapons subsystem does not cause a negative impact to other subsystems on the air vehicle.

Measurements for additional weapons include weapon accuracy and effectiveness measurements. These measurements should provide data to demonstrate total system integration and accuracy performance including detection, aiming, firing, and guidance as required.

8-18 FAULT TOLERANT SYSTEMS

Fault tolerant subsystems provide various degrees of redundancy in a subsystem in order to allow the subsystem to operate at either full or reduced capability in the event of a failure in one of its components. Fault tolerance may be achieved with either parallel redundancy or with path-switching methods. In a parallel redundant subsystem the redundant elements are capable of carrying out their function instantly upon the failure of a component without the necessity for any other intervention on the part of any other component of the subsystem. On the other hand, path-switching-type fault tolerant subsystems require some type of monitor to detect a failure has occurred and a switching device to switch to the backup component, subsystem, or system.

An example of a parallel redundant subsystem is a structural subsystem (such as a rotor blade retention subsystem made up of numerous individual elements) with multiple structural members arranged so that the failure of one (or perhaps more) element does not result in the failure of the subsystem. Demonstration of the capability of such a redundant subsystem can be achieved by intentionally failing individual structural elements and showing that the subsystem as a whole still provides the necessary structural integrity. Specific criteria must be established as to the number of structural elements that can fail before the subsystem can be considered no longer usable. In such a redundant subsystem it is important to be able to detect by inspection or through other means that an individual structural member failed so that appropriate repair or replacement action can be taken. Path-switching methods require that failure-sensing and switching elements be incorporated into the subsystem to allow for failure detection and appropriate switching to a backup subsystem. An example of an electrical or software subsystem providing path switching is a digital bus control subsystem that incorporates primary and backup bus controllers. Active software control devices monitor the proper operation of the primary bus controller and switch control to the backup controller if the primary controller fails. Critical to the proper operation of a fault tolerant system such as this is the reliability of the sensing and switching elements. In addition, the switching must occur in a sufficiently rapid manner so critical system functions are not disrupted.

8-19 SOFTWARE CONFIGURATION ITEMS AND EMBEDDED SOFTWARE INTEGRATION

The term “computer software configuration item” (CSCI), defined in MIL-STD-498, *Defense System Software Development*, (Ref. 67) applies to the computer software form of a configuration item as designated by a contracting agency. Basically, it refers to a collection of software source codes that constitute a configuration managed item. CSCIs are not necessarily measured or partitioned by any logical, functional, or physical constraints or requirements. They are frequently allocated in conjunction with the associated hardware configuration items (HWCI) on which they may reside or are executed.

The term “embedded integration” as it relates to qualification testing refers to verification of the performance of integrated hardware/software, which cannot otherwise be tested at the CSCI formal qualification test (FQT) level. Residence upon and integration with some form of computer resource device (firmware or hardware) allow the CSCI logic to perform the subsystem- or system-level functional operations.

Other than validating subsystem- or system-level performance, only verification at the interfaces can provide an intermediate test level of confidence beyond CSCI FQT. Refer to ADS-32, *Airborne Digital System Integration and Testing*, (Ref. 68) for additional detailed guidance on this topic as it relates to airworthiness qualification.

8-19.1 SOFTWARE CONFIGURATION ITEMS

For qualification purposes, CSCIs typically must pass an FQT that involves formally testing approved and documented requirements in accordance with approved and documented test cases and then documenting the results. The three MIL-STD-498 (Ref. 67) data item descriptions (DIDs) used for the documents discussed in this subparagraph are DI-IPSC-81433, *Software Requirements Specification (SRS)*, (Ref. 69); DI-IPSC-81439, *Software Test Description (STD)*, (Ref. 70); and DI-IPSC-81440, *Software Test Report (STR)*, (Ref. 71).

CSCIs are built up from an aggregate of smaller logical parts. These parts are defined in MIL-STD-498 (Ref. 67). By definition, the smallest part that is a separately testable entity is the computer software unit (CSU). The computer software component (CSC) is defined as a distinct part of a CSCI and is made up of a collection of CSUs. Finally, the CSCI is made up of a collection of CSCs. CSU- and CSC-level tests are not considered qualification tests. They are documented in software development folders (SDF) as are their results and follow-up corrective actions. FQT is recognized as a qualification test for CSCIs but does not suffice for airworthiness qualification because it occurs prior to integration with hardware and subsystem- and system-level testing. Therefore, higher level testing should not only test software in the sense of how well the software has been implemented but also of how the system design and function operates to support successfully the subsystem- or system-level test objectives. Refer to ADS-32 (Ref. 68) for additional guidance on integration testing requirements affecting airworthiness qualification.

The requirements to be tested and validated for CSCI qualification purposes in FQT are those that are documented in DI-IPSC-81433 (Ref. 69). The procedures and final reports of FQT are documented in DI-IPSC-81439 (Ref. 70) and DI-IPSC-81440 (Ref. 71).

8-19.1.1 Software Requirements Specification

The SRS document is prepared on a per CSCI basis. The SRS contains the engineering and qualification requirements for a CSCI that should be tested during the FQT phase of software development. These requirements are essentially derived from the functions that are allocated in DI-IPSC-81432, *System/Subsystem Design Document (SSDD)*, (Ref. 72) and specified in DI-IPSC-81431, *System/Subsystem Specification (SSS)*, (Ref. 73), for accomplishment by software.

Each SRS requirement is independently testable at the CSCI level but not necessarily at lower or higher levels. The SRS should identify the requirements that follow:

1. Internal/external interfaces
2. Capabilities
3. Detailed data elements
4. Site/environment/installation-dependent data
5. Operational parameters
6. Sizing and timing specifics
7. Safety specifics
8. Design constraints
9. Security specifics
10. Human factors
11. Traceability
12. Quality specifics
13. Qualification methods.

8-19.1.2 SOFTWARE TEST DESCRIPTION

The STD document is prepared on a per CSCI basis. The STD contains the descriptions of the individual test cases that are used to validate performance against the SRS requirements to be tested during the FQT phase. The STD also describes pretest procedures, hardware preparation procedures, and software preparation procedures. Each SRS requirement has a corresponding STD test case. For each unique test case identifier, the STD should describe

1. The SRS requirement being tested
2. Assumptions and constraints
3. Detailed conditions for test case hardware/software initialization
4. Detailed procedures
5. Detailed inputs

6. Expected test outputs
7. Evaluation criteria.

8-19.1.3 SOFTWARE TEST REPORT

The STR document is prepared on a per CSCI basis. The STR is a permanent record of the results of the performance of FQT for a CSCI. The STR summarizes tests performed, results, hardware and software configurations used/tested, test conductors and witnesses, problems encountered, and backup test steps. The STR also identifies individual test cases, test case results, and rationale/impact of test case procedure deviations. For management purposes the STR provides evaluations of the CSCI, specific test results, CSCI deficiencies/ limitations/constraints, and recommendations for improvement of the CSCI design, operation, or testing thereof.

8-19.2 EMBEDDED SOFTWARE INTEGRATION

Once the software has passed the FQT phase, integration testing becomes an exercise in verifying subsystem- or system-level functionality. As much as is physically possible, each interface that is incorporated when a configuration item is integrated in the buildup of a subsystem or system should be tested to verify operation or data reliant on the functioning of that interface.

Software is integrated in many different ways and at many different levels; examples of these are developer to developer, CSU to CSU, CSU to CSC, CSC to CSC, CSC to CSCI, CSCI to CSCI, and CSCI to HWCI. These levels of integration are accomplished in many different ways from informal communication to informal internal interface documents to formally documented interfaces identified in interface requirements specifications (IRS), interface control documents (ICD), etc. Dependent upon the formality of the interface controls, qualification testing is usually limited to verification of the documented interfaces and performance validation at the integrated subsystem/system level.

8-19.2.1 Software/Hardware Integration

Software must be integrated with hardware to perform any usable function. Each step of the integration process should be followed by testing, preferably also regression testing, to assure that integration does not uncover unforeseen complications or introduce new problems. Regression testing includes the retesting of previously tested functions when a new function is added or a change is made. At the lower levels of integration, testing is informal and more reliant on the thoroughness of the developers. As levels of integration become higher and more formalized, testing should focus on verifying the documented interfaces and on successful accomplishment of subsystem- or system-level requirements.

8-19.2.2 Integration Test Requirements

The interface requirements that should be tested and validated in FQT are those that are documented in the DI-IPSC-81434, *Interface Requirements Specification (IRS)*, (Ref. 74). This DID specifies the requirements for all interfaces between one or more CSCIs and other configuration items or critical items. As stated previously, FQT is not a subsystem- or system-level test suitable for airworthiness qualification.

To assure the valid integration of software and hardware, several steps can be taken. First, the operating procedures that guide informal and formal integration and testing should be standardized and followed. During the development or modification of formal interfaces, documents such as the IRS and ICDs, strict overview, and control and participation by developers, integrators, testers, and users via an Interface Control

Working Group (ICWG) should occur. Technical reviewers should continually evaluate the correctness of interfaces for required data, defined types and limits, units, scaling factors, sources, destinations, timing requirements and impacts, fault tolerance of data, etc.

ADS-32 (Ref. 68) contains additional detailed guidance on the topic of integration test requirements as it relates to subsystem- or system-level airworthiness qualification.

8-20 TEST-ANALYZE-FIX-TEST (TAFT)

The results of subsystem level qualification testing form a part of the overall TAFT cycle in which performance or reliability issues uncovered during test are analyzed as to root cause, corrective actions are developed and implemented into the hardware or software, and the system is subjected to additional testing until it has been determined that the corrective action has adequately addressed the previously uncovered problem. This is part of a continuing process and may require that corrective actions be evaluated first by component-level tests prior to incorporation into subsystem-level testing. It may also be decided that incorporation of corrective action and retest may be performed with little additional risk at the system level. Typically the PA would approve TAFT decision, however, this is becoming a task allocated to Integrated Product Teams (IPT).

REFERENCES

1. ADS-9B, *Propulsion System Technical Data*, US Army Aviation Research and Development Command, St. Louis, MO, October 1980.
2. ADS-39A (draft), *Substantiation Requirements for Alternate Manufacturing Sources of Helicopter Drive System Components*, US Army Aviation and Troop Command, St. Louis, MO, April 1996.
3. ADS-50-PRF, *Rotorcraft Propulsion Performance and Qualification Requirements and Guidelines*, US Army Aviation and Troop Command, St. Louis, MO, 24 April 1996.
4. MIL-E-8593A, *General Specification for Turboprop Aircraft Engine*, 15 October 1975.
5. MIL-E-87231, *Turbojet and Turbofan Aircraft Engines*, 15 April 1986.
6. ADS-25, *Engine Performance Data*, US Army Aviation Systems Command, St. Louis, MO, October 1984.
7. MIL-T-5624P, *Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8ST*, 29 September 1992.
8. MIL-L-23699E, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base,* NATO Code #0-156, 23 November 1994.
9. MIL-L-7808K, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base*, 20 July 1994.
10. AV-E-8593D, *Engine Aircraft, Turboshaft and Turboprop, General Specification for,* US Army Aviation Systems Command, St. Louis, MO, 25 October 1994.
11. ADS-26, *Engine Installation Data*, US Army Aviation Systems Command, St. Louis, MO, October 1984.
12. MIL-T-5955C, *Transmission Systems, VTOL-STOL, General Requirements for,* 17 September 1970.
13. ADS-17C, *Power Units: Aircraft Auxiliary, Gas Turbine Type IV,* US Army Aviation Systems Command, St. Louis, MO, March 1989.
14. TR 89-D-22E, *Aircraft Crash Survival Design Guide, Vol. 5, Aircraft Postcrash Survival*, US Army Research and Technology Activity, Fort Eustis, VA, December 1989.
15. MIL-STD-1290A, *Light Fixed, and Rotary Wing Aircraft Crash Resistance*, 26 September 1988.
16. MIL-STD-6053C, *Tests Impact, Shock Absorber Landing Gear, Aircraft*, 27 September 1989.
17. ADS-29, *Structural Design Criteria for Rotary Wing Aircraft*, US Army Aviation Systems Command, St. Louis, MO, September 1986.
18. ADS-36, *Rotary Wing Aircraft Crash Resistance*, US Army Aviation Systems Command, St. Louis, MO, 1 May 1987.
19. MIL-STD-704E, *Aircraft Electric Power Characteristics*, 1 May 1991.
20. MIL-STD-7080, *Selection and Installation of Aircraft Electronic Equipment*, 31 May 1994.
21. MIL-E-7016F, *Electric Load and Power Source Capacity Aircraft, Analysis of,* 15 April 1988.
22. MIL-I-8700A, *Installation and Test of Electronic Equipment in Aircraft, General Specification for,* 28 February 1992.
23. MIL-STD-877, *Antenna Subsystem, Airborne, Criteria for Design and Location of*, 8 November 1968.

24. MIL-B-5087B, *Bonding, Electrical, and Lightning Protection for Aerospace Systems*, 9 December 1992.
25. MIL-STD-765A, *Compass Swinging, Aircraft, General Requirements for,* 26 February 1988.
26. FAAAC 20-121A, *Airworthiness Approval of Airborne LORAN-C Navigation Systems for Use in the US National Airspace System (NAS),* US Government Printing Office, Washington, DC, 24 August 1988.
27. FAAAC 20-130, *Airworthiness Approval of Multi-Sensor Navigation Systems for Use in the US National Airspace System (NAS) and Alaska*, US Government Printing Office, Washington, DC, 12 September 1988.
28. FAAAC 20-101C, *Airworthiness Approval of OMEGA/VLF Navigation Systems for the United States NAS and Alaska*, US Government Printing Office, Washington, DC, 12 September 1988.
29. ADS-41, *Hybrid Navigation System Performance Flight Testing, Rotary Wing Aircraft*, US Army Aviation Systems Command, St. Louis, MO, April 1990.
30. ADS-23, *Lighting, Aircraft, Interior, AN/AVS-6 Aviators Night Vision Imaging System Compatibility*, US Army Aviation Systems Command, St. Louis, MO, May 1981.
31. MIL-STD-1553B, *Aircraft Internal Time Division Command/Multiplex Data Bus*, 12 February 1980.
32. MIL-HDBK-1553A, *Multiplex Application Handbook*, 31 January 1993.
33. MIL-STD-1760B, *Aircraft/Store Electrical Interconnection System*, 25 June 1993.
34. AS 4115, *Data Bus Systems Test Plan*, Society of Automotive Engineers, Warrendale, PA, 11 January 1989.
35. MIL-STD-850E, *Aircrew Station Vision Requirements for Military Aircraft*, 7 June 1991.
36. *1988 Anthropometric Survey of US Army Personnel: Methods and Summary Statistics,* Natick/TR-89/044, US Army Natick Research, Development, and Engineering Center, Natick, MA, September 1989.
37. MIL-STD-1294A, *Acoustical Noise Limits in Helicopters*, 12 August 1985.
38. MIL-A-8806A, *Acoustical Noise Level in Aircraft, General Specification for*, 11 July 1966.
39. MIL-STD-1474C, *Noise Limits for Military Materiel (Metric)*, 30 July 1993.
40. MIL-S-58095A, *Seat System, Crash Resistance, Nonejection, Aircrew, General Specification for*, 31 January 1986.
41. MIL-S-85510, *Seats, Helicopter Cabin, Crashworthy, General Specification for*, 19 November 1981.
42. MIL-STD-1288, *Aircrew Protection Requirements Nonnuclear Weapon Threat*, 24 August 1981.
43. 14 CFR, Part 25, *Airworthiness Standards: Transport Category Airplanes*, US Government Printing Office, Washington, DC, 1 January 1994.
44. TR 89-D-22A, *Aircraft Crash Survival Design Guide, Vol. 1, Design Criteria and Checklist*, US Army Research and Technology Activity, Fort Eustis, VA, December 1989.
45. 14 CFR, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic and Commuter Category Airplanes*, US Government Printing Office, Washington, DC, 1 January 1994.
46. 14 CFR, Part 27, *Airworthiness Standards: Normal Category Rotorcraft*, US Government Printing Office, Washington, DC, 1 January 1994.
47. 14 CFR, Part 29, *Airworthiness Standards: Transport Category Rotorcraft*, US Government Printing Office, Washington, DC, 1 January 1994.

48. AFGS-87226A, *Oxygen Systems, Aircraft, General Specification for*, 1 April 1992.
49. MIL-D-8683C, *Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for*, 5 February 1988.
50. MIL-D-85520AS, *Design and Installation of Onboard Oxygen-Generating Systems in Aircraft, General Specification for,* 16 January 1991.
51. 14 CFR, Part 91, *General Operating and Flight Rules*, US Government Printing Office, Washington, DC, 1 January 1994.
52. TSO-78, *Crew Member Demand Mask, Oxygen*, Federal Aviation Administration, Washington, DC, 7 January 1967.
53. TSO-89, *Oxygen Regulator, Demand*, Federal Aviation Administration, Washington, DC, 7 January 1967.
54. ADS-30, *Human Engineering Requirements for Measurements of Operator Workload*, US Army Aviation Systems Command, St. Louis, MO, 17 November 1986.
55. MIL-H-18325B, *Heating and Ventilating Systems Aircraft, General Specification for*, 4 May 1959.
56. MIL-T-18606, *Test Procedures for Aircraft Environmental Systems*, 31 October 1969.
57. TB MED 507, *Occupational and Environmental Health Prevention, Treatment, and Control of Heat Injury*, 25 July 1980.
58. MIL-T-5842, *Transparent Areas on Aircraft Surfaces (Windshield and Canopies), Rain-Removing and Washing Systems for Defrosting, Deicing, Defogging, General Specification for*, 29 March 1995.
59. MIL-T-18607A, *Thermal and Fluid Anti-Icing Systems and Equipment, Aircraft External Surfaces*, 1 June 1993.
60. 29 CFR, Part 1910.1000, Subpart Z, *Toxic and Hazardous Substances, Air Contaminants, Permissible Exposure Limits*, US Government Printing Office, Washington, DC, 21 February 1995.
61. DoD Instruction 6055.1, *DoD Occupational Safety and Health Program*, 21 October 1984.
62. *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants, Vols. 4 and 5*, Committee on Toxicology, Board on Toxicology and Environmental Health Hazards, National Research Council, Washington, DC, 1985.
63. MIL-STD-1425A, *Safety Design Requirements for Military Laser and Associated Equipment*, 30 August 1991.
64. ADS-20, *Armament/Fire Control System Survey*, US Army Aviation Systems Command, St. Louis, MO, April 1976.
65. MIL-H-8591H, *Airborne Stores, Suspension Equipment and Aircraft-Store Interface (Carriage Phase): General Design Criteria for*, 23 March 1990.
66. MIL-STD-209H, *Slinging and Tie-Down Provisions for Lifting and Tying Down Military Equipment*, 28 June 1991.
67. MIL-STD-498, *Software Development and Documentation*, 5 December 1994.
68. ADS-32A, *Airborne Digital System Integration and Testing*, US Army Aviation Systems Command, St. Louis, MO, April 1991.
69. DI-IPSC-81433, *Software Requirements Specification (SRS)*, 5 December 1994.
70. DI-IPSC-81439, *Software Test Description (STD)*, 5 December 1994.
71. DI-IPSC-81440, *Software Test Report (STR)*, 5 December 1994.
72. DI-IPSC-81432, *System/Subsystem Design Document (SSDD)*, 5 December 1994.

73. DI-IPSC-81431, *System/Subsystem Specification (SSS)*, 5 December 1994.
74. DI-IPSC-81434, *Interface Requirements Specification (IRS)*, 5 December 1994.